AD-A274 146

WL-TR-93- 4111

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ALUMINUM ALLOY 8090-T8771 THICK PLATE MATERIAL CHARACTERIZATION

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October 1993

Interim Report October 1991 to May 1993

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1993

3. REPORT TYPE AND DATES COVERED
Interim 10/91 to 5/93

4. TITLE AND SUBTITLE
Aluminum Alloy 8090 - T8771 Thick Plate Material Characterization

5. FUNDING NUMBERS
62102F
2418
04
81
F33615-90-C-5915

6. AUTHOR(S)
Russell R. Cervay

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Dayton Research Institute
300 College Park
Dayton, Ohio 45469-0136

8. PERFORMING ORGANIZATION REPORT NUMBER
UDR-TR-93-71

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Materials Directorate
Wright Laboratory
Air Force Materials Command
Wright-Patterson AFB, OH 45433-7734

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
WL-TR-93-4111

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release; Distribution is Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The purpose of this study was to evaluate the mechanical properties of Al-Li alloy 8090, 1.750 inch, thick plate thermally processed to the T8771 condition. Room temperature properties evaluated were: tensile, compression, bearing, and shear strengths, fracture toughness, notched and smooth fatigue, constant amplitude and variable amplitude fatigue crack growth rate.

Constant amplitude fatigue crack growth rate test data was generated at two load-ratios, 0.1 and 0.33, and in both laboratory air and saturated air environments.

As expected, tensile properties were acceptable for the various specimens orientations removed from the plate's rolling plane: there was a significant drop in yield strength for in-plane specimens oriented 45 degrees off the rolling direction. Also, through-the-thickness ductility was quite low.

Compression, bearing, shear and fatigue properties were all good for the specimen orientations examined.

The fracture toughness was acceptable for specimens with a L-T and T-L orientations: for through-the-thickness loading, i.e. S-L orientation, the toughness was cut in half. (Continued)

14. SUBJECT TERMS
AL8090, Aluminum-Lithium, Bearing, Shear, Tensile, Fatigue, Fracture Toughness, Relative Humidity

15. NUMBER OF PAGES
63

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

13. ABSTRACT (Continued)

The material showed superior fatigue crack resistance attributable to considerable crack closure induced by very course crack faces. The exceptional surface roughness is characteristic of a mostly unrecrystallized grain structure in Al-Li materials. The high level of closure is manifested as a plateau of nearly constant fatigue crack growth rate over the normally linear log-da/dN versus log ΔK mid-range seen in conventional high strength aluminum products and Al-Li materials having a recrystallized grain structure. The plateau diminished when the R-ratio was raised to equal 0.33 and was not present in the data generated in saturated air environment. In both environments the data sets for the two R-ratios plot in overlapping scatter bands. For growth rates above the near threshold region the saturated air environment increased the crack velocity.

FOREWORD

This technical report presents work conducted at the Materials Engineering Branch, Systems Support Division, Wright Laboratories Material Directorate by the University of Dayton Research Institute, Dayton, Ohio under Contract F33615-90-C-5915, "Quick Reaction Evaluation of Materials and Processes." Mr. Neal Ontko serves as current contract monitor.

Testing took place over the period from October 1991 to May 1993.

The author would like to extend recognition to Messrs. Robert Pinella of Wright Laboratory and Donald Woleslagle, John Eblin and Robert Hicks of the University of Dayton for conducting the tests.

This report was submitted by the author in August 1993.

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SECTION 1
INTRODUCTION

During the late 1970's polymeric composites were replacing 2000 and 7000 series wrought aluminum parts of aerospace structures at an escalating rate because a lighter stiffer structure was obtained by optimally orienting the fiber reinforcement in the composite's principle loading direction. The trend drew a decisive response in the early 1980's; accelerated development of the aluminum-lithium family of alloys. The step was costly because, (1) the accelerated pace of the research was reminiscent of the race to put a man on the moon of the presidents Kennedy-Johnson era, and (2) the step required the erection of new facilities dedicated to the production of Al-Li products.

The addition of 2 to 3 weight percent lithium to aluminum reduces the resulting alloy's density by 6 to 9 percent [1], Figure 1, and increases the modulus of rigidity by 8 to 12 percent [2], as shown in Figure 2. The increase in specific modulus (modulus of elasticity/density) was enough to once again make an aluminum components influence on aircraft performance competitive with that of most polymeric composite counterparts.

The first generation aluminum-lithium products, in the early 1980's, possessed slightly lower strength and inferior ductility and toughness when compared to then contemporary cleaner conventional 2000 and 7000 aluminum alloy wrought products [1,3]. In the mid-1980's these short comings were considerably improved upon; the most significant step was the adoption of the T8 thermal processing [1,4,5]. In particular, following solution heat treatment, a sheet or plate was stretched by 2 to 4 percent via cold rolling, and then artificially aged at a low temperature, 150° Celsius [6] to peak strength.

In addition to the improvement in density and modulus the Al-Li alloys have the additional positive quality of being more damage tolerant, i.e. more resistant to fatigue crack propagation, than the conventional high strength aluminum alloys. This behavior is primarily attributable to crack closure, where the crack remains closed and stationary for a portion of a fatigue load cycle [7,8]. Crack closure found in the Al-Li alloy materials has been attributed to their anisotropy causing crack tip shielding via roughness of the fatigue crack faces [3,9-17]. Of the various Al-Li products the effect is more noticeable in thick section wrought products, like the test material, where larger, mostly unrecrystalized grains possess a more anisotropic microstructure and stronger

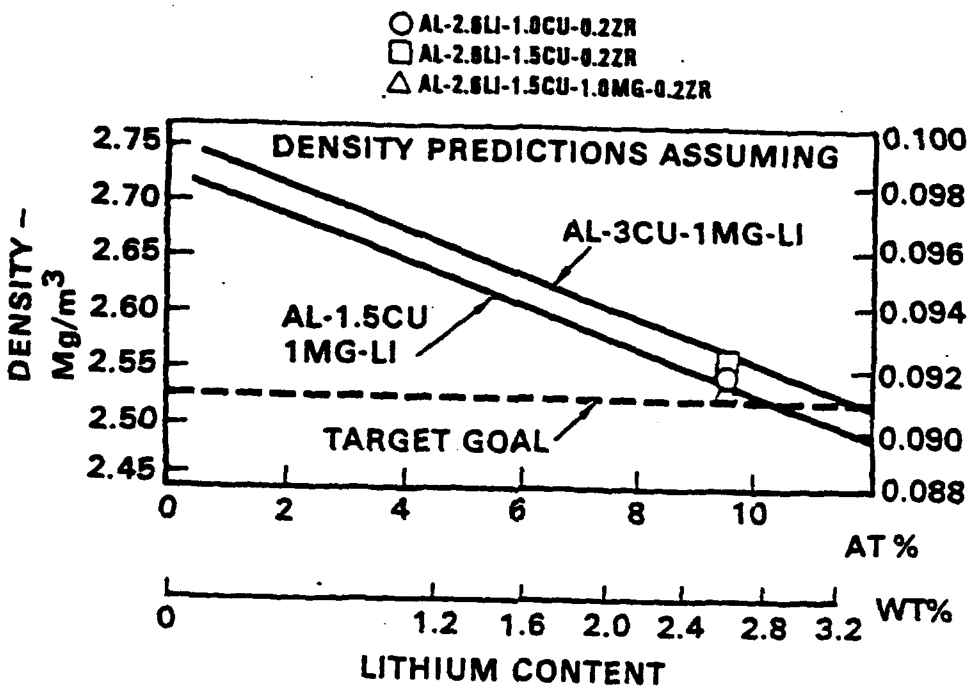


Figure 1. Al-Li alloy variation in density with Li addition[1].

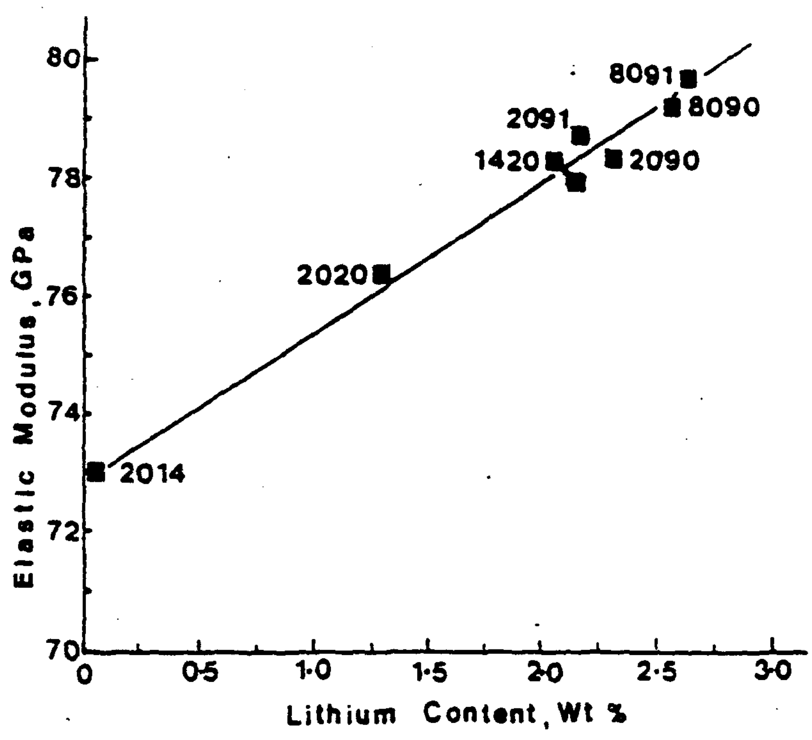


Figure 2. Al-Li alloy variation in elastic modulus with Li addition[2].

texture resulting in greater surface roughness induced closure [1,18-20]. The closure results in a reduced effective crack driving parameter and a slower fatigue crack propagation rate when compared to conventional aluminum products or Al-Li alloy products [19-23] having a recrystallized grain structure.

A further increase in fatigue crack growth resistance has also been shown to occur in Al-Li alloys possessing a high Li/Cu ratio, like that of the test material. A high Li/Cu ratio increases fatigue crack resistance, because (1) the coarseness of the crack surface increase with the Li/Cu ratio [24], (2) a low Cu content reduces the formation of embrittling secondary phase particles [1], and (3) in a moist environment the increase in oxide debris bridging the crack increases with the Li/Cu ratio, since Li promotes oxidation while Cu inhibits oxidation and resulting crack closure [1,14,24-27].

SECTION 2
MATERIAL, SPECIMENS AND PROCEDURES

The test material, produced by ALCAN, was a 1.750 inch thick Al-Li alloy 8090 plate. The material had been thermally processed to a T8771 condition. The chemical constituency, in weight percent, was as follows:

TABLE 1
CHEMICAL COMPOSITION OF 8090 Al-Li ALLOY IN WEIGHT PERCENT

Li	Cu	Mg	Zr	Fe	Si	Al
2.23	1.12	0.72	0.115	0.103	0.059	Balance

The Li/Cu ratio equals 2.0 which is high for a Al-Li alloy.

The tensile specimen is presented in Figure 3; a miniature specimen used in determining through the thickness tensile properties is shown in Figure 4. The smooth and notched fatigue specimens are illustrated in Figures 5 and 6, respectively. Compact tension specimens, Figure 7, used for fracture toughness testing had a thickness of 0.667 or 1.500 inches; the fatigue crack growth rate test specimen's thickness equalled 0.250 inch. The two Amsler shear pin specimens are illustrated in Figure 8 and the compression specimen is shown in Figure 9. The bearing specimen is depicted in Figure 10; the e/d ratio equalled 1.5 for all tests. The specimen used for the spectrum fatigue test was a standard ASTM E647 4-inch wide center cracked panel as depicted in Figure 11.

The ASTM standard test procedure adhered to during this material evaluation are capsulated in Table 2.

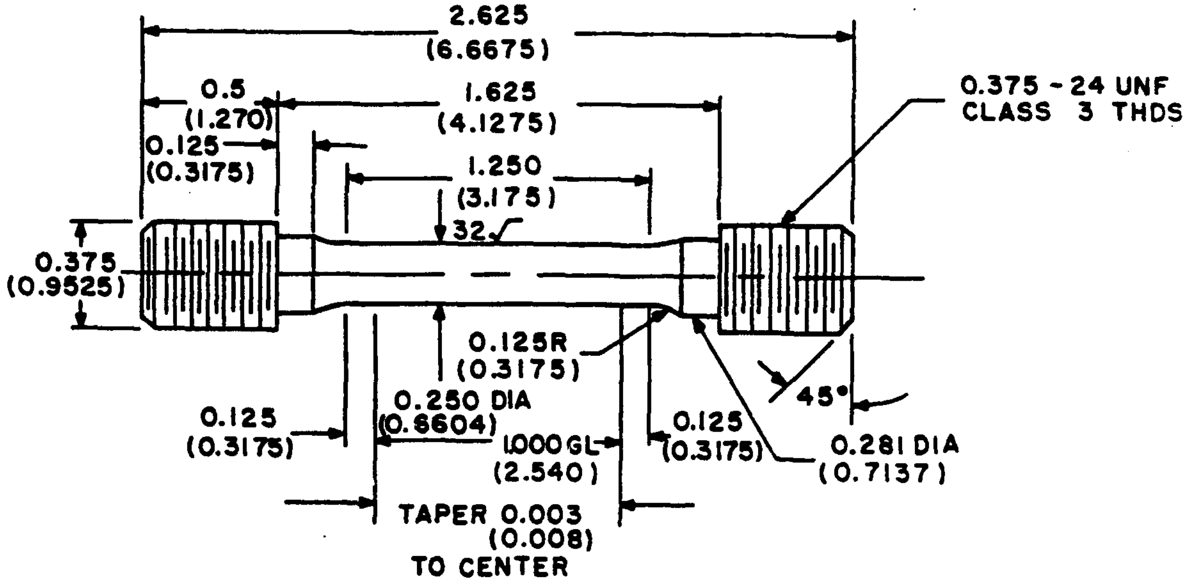
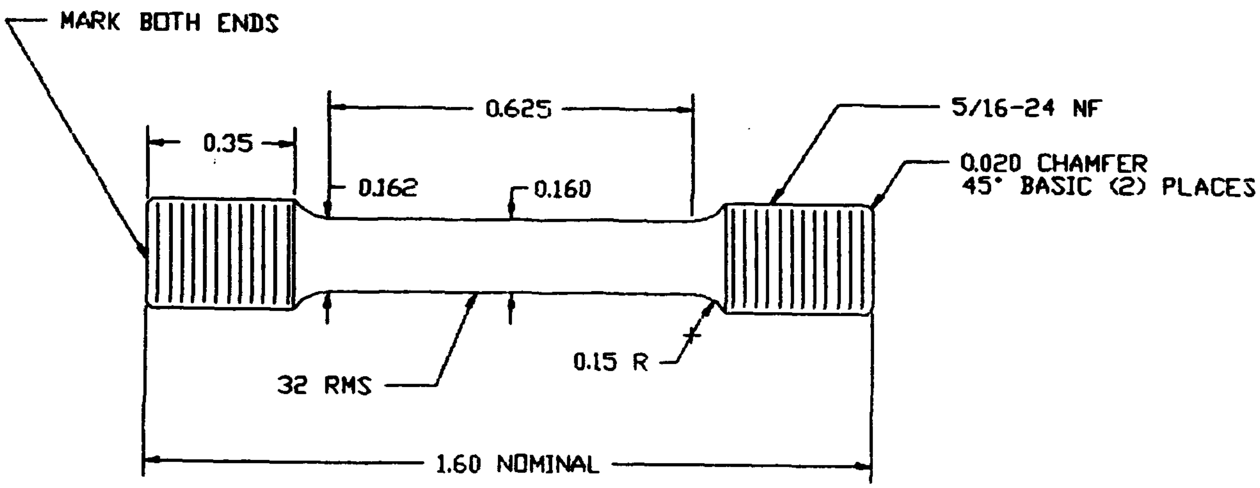
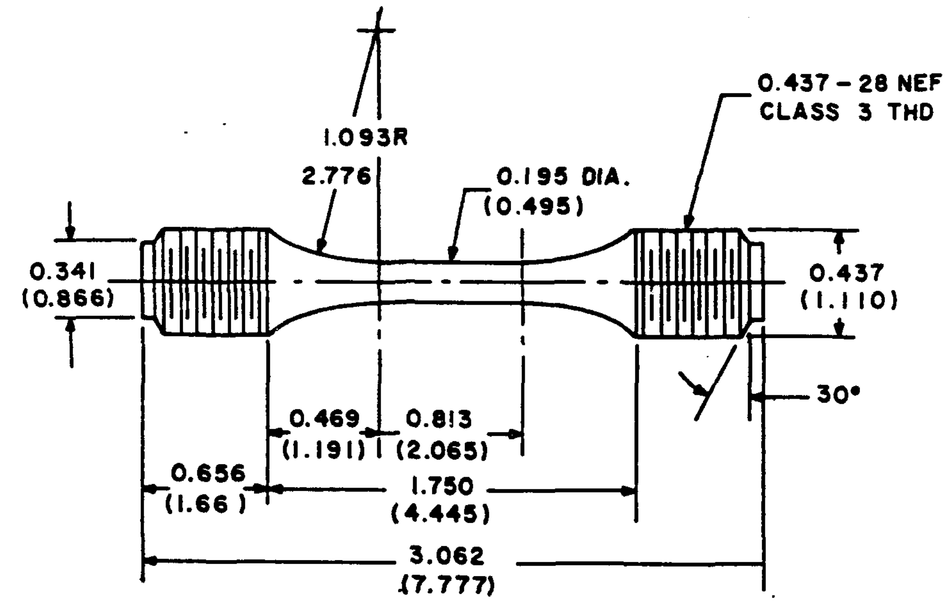


Figure 3. Standard tensile specimen configuration.



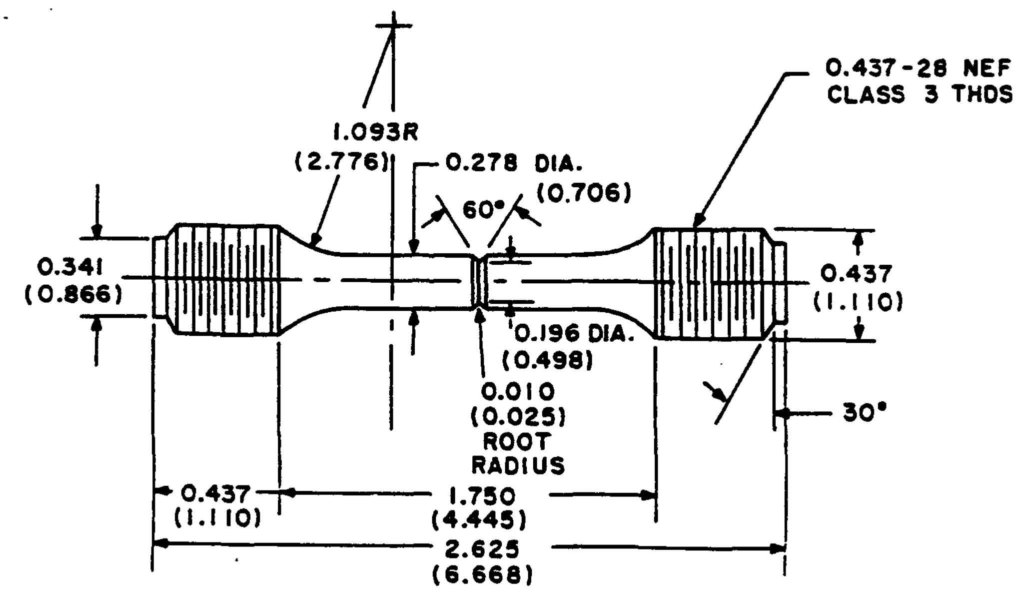
( ) DIMENSIONS IN INCHES

Figure 4. Minature tensile specimen configuration.



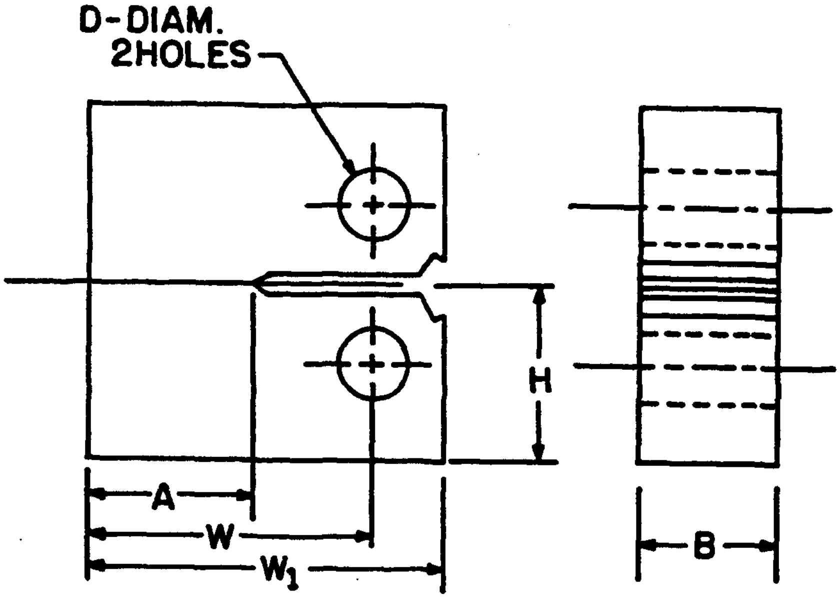
( ) DIMENSIONS IN CENTIMETERS

Figure 5. Smooth fatigue specimen configuration.



( ) DIMENSIONS IN CENTIMETERS

Figure 6. Figure notch fatigue specimen configuration.



DIMENSIONS (inches)

Specimen Size, B	A	B	W	W_1	H	D
1.500	1.650	1.500	3.000	3.750	1.800	0.630
0.667	1.000	0.667	1.333	1.666	0.800	0.375
0.250	1.250	0.250	2.000	2.500	1.200	0.500

Figure 7. Compact specimen configuration; with the thickness equalling 0.667 or 1.650 inches for fracture toughness testing and equalling 0.250 inch for fatigue crack growth rate tests.

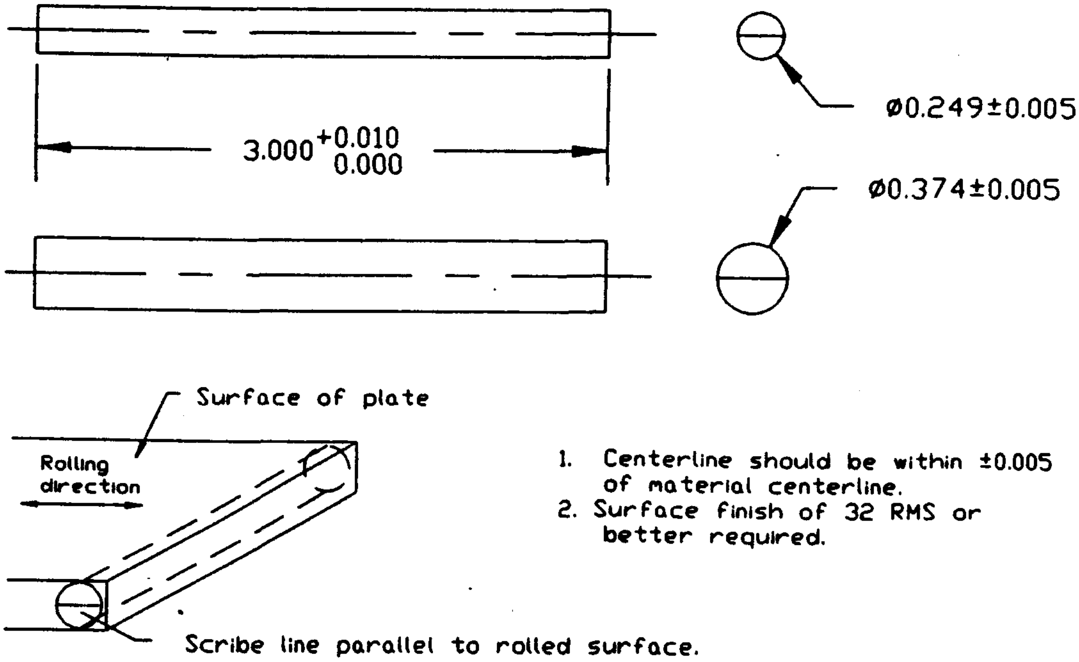


Figure 8. Amsler shear pin specimen configuration.

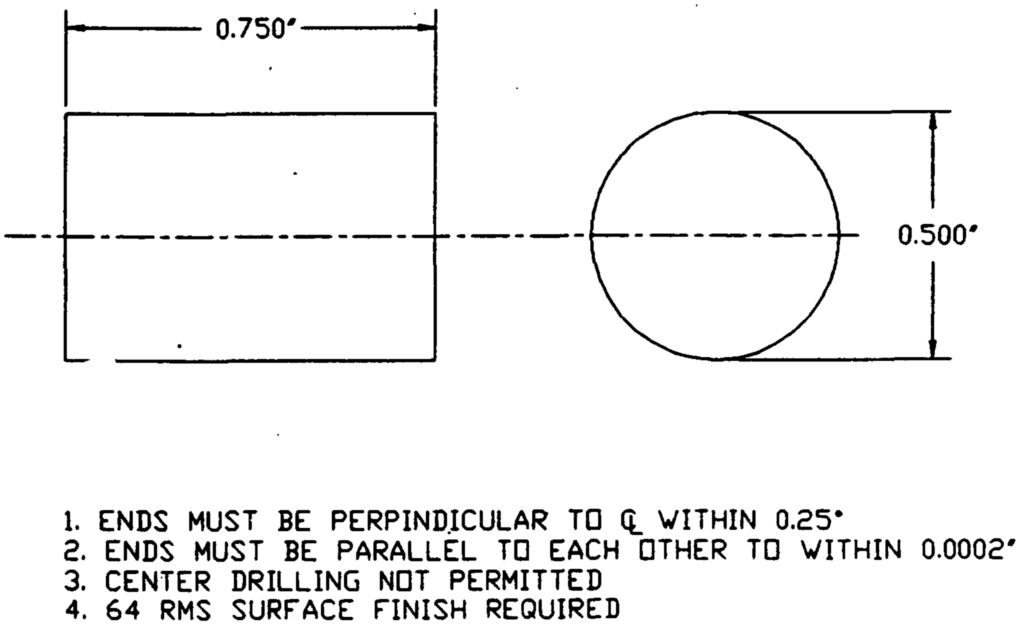
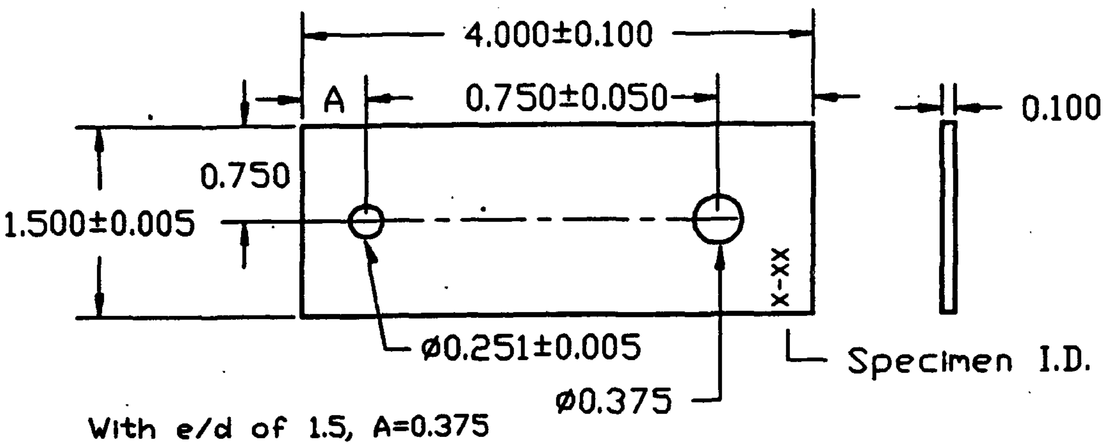


Figure 9. Compression specimen configuration.



1. Thickness 0.100 must be taken from the center of the material supplied.
2. Centerline of thickness must be +/-0.005" with centerline of material supplied.
3. Final test hole 0.251+/-0.005 to be Bored of Reamed to yield 32 RMS Remainder of specimen to be 64 RMS preferred.
4. DO NOT DEBURR OF BREAK EDGE OF FINAL TEST HOLE IN ANY WAY!!

Figure 10. Bearing specimen configuration.

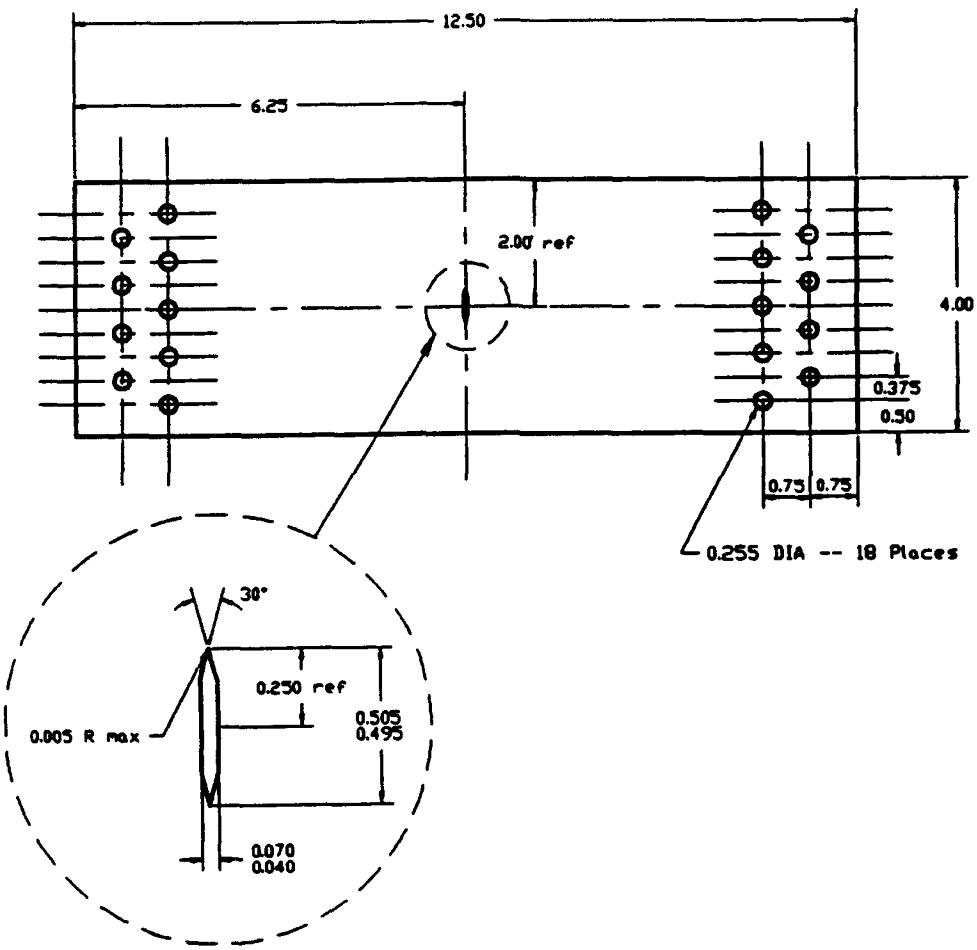


Figure 11. Spectrum fatigue center cracked panel configuration.

TABLE 2

ASTM STANDARD TEST PRACTICE

TYPE TEST	ASTM STANDARD PRACTICE
Tensile Properties	E 8-90a
Compressive Properties	E 9-89
Fatigue Life	E 466-82
Fracture Toughness	E 399-90
Fatigue Crack Growth Rate	E 647-91
Bearing Strength	E 238-84
Shear Strength	B 769-87

SECTION 3
RESULTS AND DISCUSSION

Tensile test results are presented in Table 3. The ultimate and yield strengths are good. As found with other Al-Li materials the yield strength is lowest 45 degrees off the rolling direction[11]. The ductility, as indicated by the permanent elongation, is acceptable for specimens removed from the plate's rolling plane. However, the through the thickness average percent elongation falls well below designers' nominally accepted minimum value of 5 percent[11,26]. The lack of ductility is attributable to nonuniform, through the thickness, distribution of the T8 cold work dislocations [4]. Dislocations

TABLE 3
ROOM TEMPERATURE TENSILE PROPERTIES FOR Al 8090-T8771 THICK PLATE

0.2% Yield Strength (KSI)	Ultimate Strength (KSI)	Reduction in Area (%)	Elongation 1 in. G.L. (%)	Modulus ($x10^{-6}$ psi)	Orientation
65.73	76.72	9.22	8.06	11.93	longitudinal
72.61	80.22	5.16	5.22	11.27	
66.04	76.68	11.57	7.94	10.77	
56.91	73.31	10.30	10.41	11.43	transverse
68.36	79.51	9.66	6.54	11.05	
57.30	73.76	11.16	10.52	10.18	
54.67	72.34	17.56	11.45	11.24	45^{o} off long
57.98	72.43	14.49	8.87	10.82	
55.53	72.51	15.41	9.82	11.18	
61.04	75.63	2.37	1.67*	10.45	short trans.
61.00	74.95	2.36	3.47*	11.81	
61.95	75.75	5.09	5.38*	10.93	

* short transverse oriented specimens had a 0.50 inch gauge length.

serve as nucleation sights for a finely dispersed precipitate. The absence of a dense dislocation populace at the mid-plane results in fewer and large precipitates and precipitate migration to the grain boundaries. Both weaken the grain boundaries and result in low ductility, toughness and reduced strength through the thickness.

The average tensile properties are represented in Table 4 along with Reference [12,28,29] data found for alloy 8090-T8 and T6 thick plate material. The tensile strength for the four T8 pieces of material are close to being equal. The ductility, as indicated by the percent of permanent elongation, was best in the test material. The data for the 2.36 inch thick plate reinforces the two shortcomings of Al-Li materials thermally processed to the T8 condition: (1) where the yield strength 45 degrees off the rolling direction is low, and (2) for thick sections, through thickness ductility is unacceptably low. Data for the 1-inch plate with a T6 heat treatment illustrates the improvement in permanent elongation and ductility the T8 processing provides over a more conventional heat treatment.

TABLE 4

AVERAGE ROOM TEMPERATURE TENSILE PROPERTIES FOR Al 8090 PLATE

Al 8090 Plate Thickness	0.2% Yield Strength (KSI)	Ultimate Strength (KSI)	Elongation in 1 inch G.L. (%)	Orientation
T8, 1.750 in.	68.13	77.87	7.07	longitudinal
test plate	60.86	75.53	9.16	transverse
	56.06	72.43	10.04	45^0 off long.
	61.33	75.44	3.51	short trans.*
T8, 2.36 in [12]	68.50	76.10	6.00	longitudinal
	62.80	75.90	5.80	transverse
	55.80	69.20	8.80	45^0 off long.
	52.60	66.60	3.00	short trans.*
T8, 1.38 in [12]	69.92	77.46	6.90	longitudinal
	69.19	77.89	7.20	transverse
	58.75	70.93	10.00	45^0 off long.
T8, 1.00 in [28]	65.20	75.20	5.40	longitudinal
	61.80	72.10	6.60	transverse
T6, 1.00 in [29]	64.97	72.81	5.10	longitudinal
	60.49	75.56	6.20	transverse
	61.85	63.81	0.70	short trans.*

* short transverse oriented specimens had a 0.50 inch gauge length.

Compression test results are presented in Table 5. The properties are good and compare directly with other alloy 8090 extrusions[30], presented in Table 6, along with the average test results for the test plate.

TABLE 5

ROOM TEMPERATURE COMPRESSION PROPERTIES FOR Al 8090-T8771

(1.750 inch thick plate)

0.2% Yield Strength (KSI)	Compression Modulus $x10^{-6}$ (PSI)	Orientation
62.47	11.808	longitudinal
63.90	11.961	
60.46	10.095	
62.47	11.819	transverse
70.88	12.037	
67.53	11.940	

TABLE 6

AVERAGE ROOM TEMPERATURE COMPRESSION PROPERTIES FOR Al 8090

Material Al 8090 plate	0.2% Yield Strength (KSI)	Compressive Modulus $x10^{-6}$ (PSI)	Orientation
T8771 test plate	63.3	11.3	longitudinal
	67.0	11.9	transverse
T8 extrusion [30]	74.9	12.1	longitudinal
	67.6	12.0	transverse
	60.2	11.8	45^{o} off long.
T6 extrusion [30]	69.7	11.8	longitudinal
	64.2	11.9	transverse

The test material's room temperature bearing properties shown in Table 7 are very good.

TABLE 7
ROOM TEMPERATURE BEARING STRENGTH for Al 8090-T8771
(1.750 inch thick plate) *

Bearing Yield Strength (KSI)	Bearing Ultimate Strength (KSI)	Orientation
90.56	112.13	longitudinal
91.55	112.78	
83.60	106.88	
89.59	109.93	transverse
90.57	112.67	
87.33	105.72	

* Pin diameter equalled 0.250 inch and the edge distance to pin diameter ratio equalled 1.500.

The average room temperature bearing strength is presented in Table 8 along with Al-Li material reference data [30,31]. The test plate's properties are the best of the three materials.

TABLE 8
AVERAGE ROOM TEMPERATURE BEARING STRENGTH FOR Al-Li MATERIALS

Material	Bearing Yield Strength (KSI)	Bearing Ultimate Strength (KSI)	Orientation
Al 8090-T8771	88.57	110.60	longitudinal
test plate	89.16	109.44	transverse
Al 8090-T651	81.80	100.90	longitudinal
extrusion[30]	78.00	86.30	transverse
Al 2091-T8X	77.50	98.00	longitudinal
plate[31]	89.00	115.30	transverse

* Pin diameter equalled 0.250 inch and the edge distance to pin diameter ratio equalled 1.500.

Room temperature shear strength results are reported in Table 9 and represented as average values in Table 10 along with Reference material [30,31] shear properties. As with the bearing strength, the test material possesses the best shear strength.

TABLE 9
ROOM TEMPERATURE AMSLER DOUBLE SHEAR STRENGTH FOR
Al 8090-T8771 (1.750 inch thick plate)

Ultimate Shear Strength (KSI)	Pin diameter (inch)	Orientation
41.09	0.2485	(T-L)
41.75	0.2485	
43.37	0.2480	
44.41	0.3720	
43.56	0.3710	
41.43	0.3700	

TABLE 10
AVERAGE ROOM TEMPERATURE SHEAR STRENGTH FOR Al-Li MATERIALS
(0.250 inch pin diameter)

Material	Orienta-tion	Type Test	Ultimate Shear Strength (KSI)
Al8090-T8771 test plate	T-L	Amsler	42.07
Al8090-T651 extrusion[30]	T-S	Amsler	35.4
Al2091-T351 plate[31]	Long.	Slotted	38.0
Al2091-T8X sheet[31]	Long	Slotted	39.3

Fracture toughness results are listed in Table 11. The invalid data are sufficiently close to being valid so as to have significance. In Table 12 the average toughness values are listed along with reference data for both Al-Li and conventional alloys. The test plate compares favorably with other Al-Li alloys plate, forging and extrusion products' toughness data [29-32]. For the alloys 8090-T651 [29] and 2090-T8 reference plate [32], like the test material, the toughness is cut in half when the material is loaded through the thickness for the reasons previously covered in the tensile data discussion on ductility.

TABLE 11
ROOM TEMPERATURE FRACTURE TOUGHNESS FOR Al 8090-T8771
(1.750 inch thick plate)

Orientation	Thickness (inch)	K_Q KSI(in)$^{.5}$	Valid K_{Ic} ?	ASTM Invalidity Criteria P_{max}/P_{min}	$P_{fatigue}/P_{max}$
L-T	1.500	24.72	No	1.17	
	1.500	27.02	Yes		
	1.500	23.67	No	1.21	
T-L	1.500	24.96	Yes		
	1.500	24.32	Yes		
	1.500	22.65	Yes		
S-L	0.660	12.14	No		0.892
	0.660	12.82	No		0.842
	0.660	9.85	No		0.771

The test material's toughness is low when compared to a conventional 2000 and 7000 series aluminum thick plate[33-38]. For the reference alloy 7475-T7651[33] plate valid (L-T) and (T-L) orientation data approaches double that of the test plate. Likewise, for the alloy 7475-T7651[33] and -T7351[34] plates, the through the thickness, (S-L) orientation valid data, more than triples that of the test plate.

TABLE 12

ROOM TEMPERATURE FRACTURE TOUGHNESS OF HIGH STRENGTH ALUMINUMS

Material	K_Q KSI(in)$^{1/2}$	Orientation	ASTM Valid?
Al 8090-T8771 test plate	27.02	L-T	Yes
	24.64	T-L	Yes
	11.60	S-L	No
Al 8090-T651 plate[29]	31.94	L-T	Yes
	29.99	T-L	Yes
	14.38	S-L	Yes
	13.92	S-T	Yes
Al 8090-T651 extrusion[30]	27.20	L-T	Yes
	15.60	T-L	Yes
Al 8090-T8 extrusion[30]	30.50	L-T	No
	14.60	T-L	Yes
Al 2090-T8E41 plate[32]	34.00	L-T	Yes
	25.00	T-L	Yes
	17.00	S-L	Yes
Al 2091-T8 plate[31]	27.50	L-T	Yes
	29.20	T-L	Yes
Al 2091-T6 forging[31]	26.20	L-T	No
	24.20	T-L	No
Al 7475-T7651 plate[33]	49.20	L-T	Yes
	44.20	T-L	Yes
	38.30	S-L	Yes
Al 7475-T7351 plate[34]	63.46	L-T	No
	59.36	T-L	No
	38.50	S-L	Yes
Al 7010-T73651 plate [35]	37.00	L-T	No
	29.90	T-L	Yes
	23.05	S-L	Yes
Al 7050-T73651 plate[36]	36.60	L-T	Yes
	32.20	T-L	Yes
Al 7075-T73511 plate[37]	43.00	L-T	Yes
	30.00	T-L	Yes
Al 2419-T851 plate[38]	34.80	L-T	Yes
	31.40	T-L	Yes
	23.00	S-L	Yes

The longitudinal notched and smooth fatigue test results are presented in Table 13 and Figures 12 and 13, along with reference data for the test alloy in the extrusion product form [30,31]. The test material's fatigue performance is good; for the smooth specimens, K_t=1.0, the test material's performance equals or exceeds that of the T651 processed extrusion reference data [30]. Likewise, for the notched fatigue results, the test material's data plots within the scatter band of the T651 extrusion reference material [30,31].

TABLE 13

NOTCHED AND SMOOTH ROOM TEMPERATURE LONGITUDINAL FATIGUE TEST RESULTS FOR Al 8090-T8771 THICK PLATE

Stress (KSI)	Total Cycles	Specimen Type
50.00	3,822	Notch
40.00	7,994	Notch
30.00	32,103	Notch
20.00	10,000,000+	Notch
20.50	103,502	Notch
28.00	39,796	Notch
26.00	74,224	Notch
24.00	65,517	Notch
22.00	135,951	Notch
21.00	648,867	Notch
29.00	10,000,000+	Smooth
43.50	2,946,918	Smooth
50.80	280,000	Smooth
57.00	93,383	Smooth
60.00	36,998	Smooth
66.00	16,366	Smooth
69.00	15,020	Smooth
48.00	95,642	Smooth
73.50	5,016	Smooth
37.50	17,000,000+	Smooth

(+ indicates test was terminated without failure)

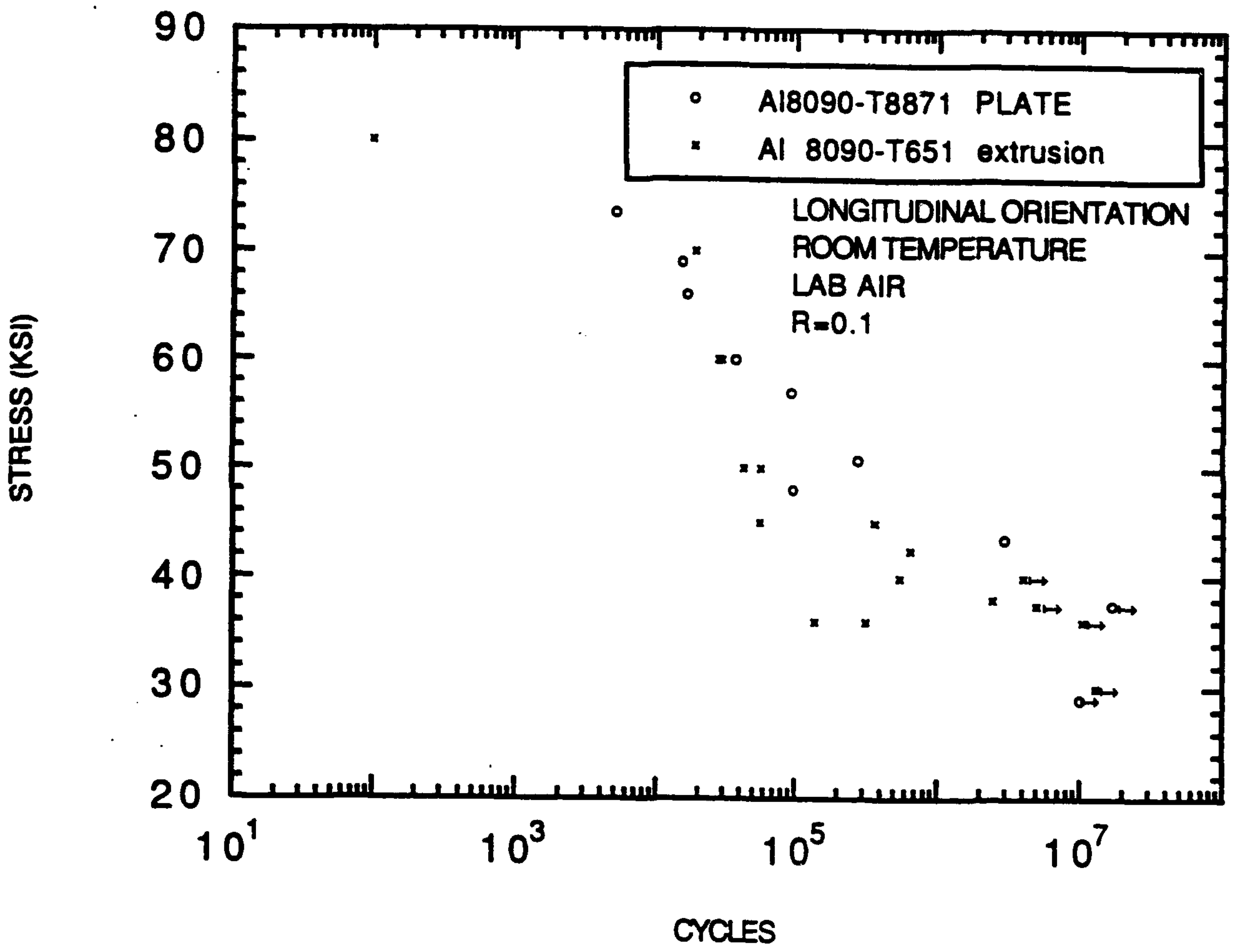


Figure 12. Smooth (K_t=1) fatigue test results Al 8090-T8771 thick plate plotted with extrusion Reference data[30].

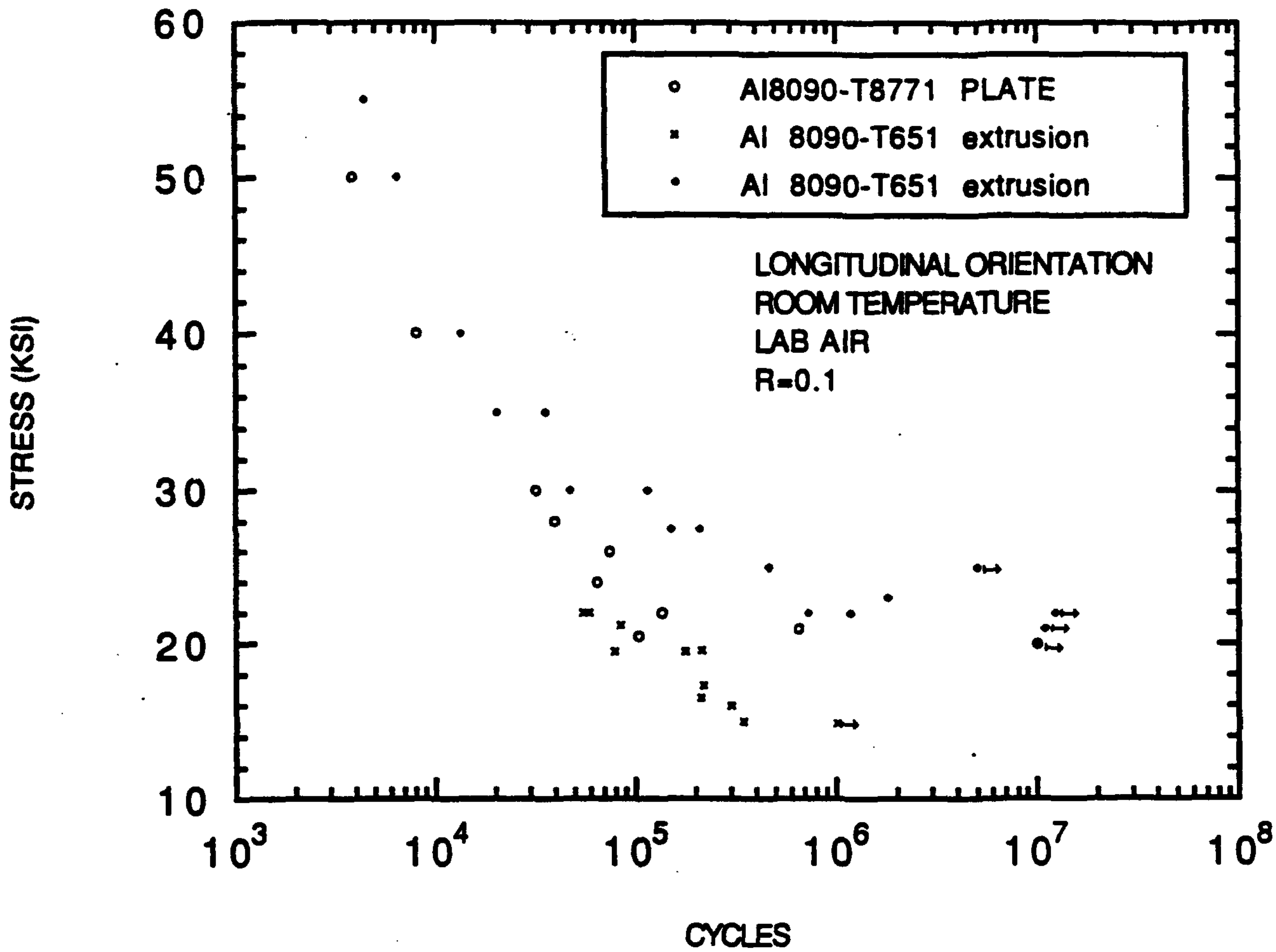


Figure 13. Notched (K_t=3) fatigue test results Al 8090-T8771 thick plate plotted with extrusion Reference data[30,31].

Constant amplitude loading fatigue crack growth rate(FCGR) data was generated in lab air and saturated air environments using two stress-ratios equalling 0.1 and 0.33; the test results are tabulated in Appendix A. The laboratory air relative humidity fluctuated over the test period from 10 to 43 percent. Fatigue crack growth rate data test results are plotted in Figures 14 through 17. The test data plots in an unusually wide scatter band for data generated using computer automated test control and data acquisition system. As expected, the material showed a great deal of crack closure, attributable to the unusually course fracture faces produced by a mostly unrecrystalized grain structure. The effective stress intensity range is also plotted (open symbol) in the four figures. The effective stress intensity range was calculated after the crack opening load was determined via the intersection method [39] from the load versus crack opening displacement (COD) traces. As seen in other Al-Li materials there was a strong closure effect for low loading conditions and with a shorter crack length; the closure effect diminishes with increased crack length [22,23,25]; thus for a K-increasing test the effective and remotely applied ΔK converge at the high end of the test data range.

The laboratory air, R= 0.1 data set shows a plateau of nearly constant or very gradually increasing velocity in the mid-range. The plateau has been observed by previous researchers for Al-Li alloys thermally processed to the T8 condition [14,18,26] and undergoing tests in a laboratory air environment. The plateau is attributed to surface roughness induced closure caused by the unusually coarse fracture face found in Al-Li thick section products with a T8 heat treatment.

The laboratory air, R= 0.1, fatigue crack growth rate data is replotted in Figure 18 along with Al-Li alloy Reference data [30,31]. The test plate shows equal or better fatigue crack growth resistance than the Reference [30,31] Al-Li extrusion or plate material.

The same data set is represented in Figure 19 along with test data for four conventional aerospace aluminum alloy wrought products [33,35,38,40]. The test material is the most damage tolerant when compared to these other materials.

The data generated in air for the two R-ratios are plotted together in Figure 20; the two data sets generated in a saturated air environment are plotted together in Figure 21. In the laboratory air environment, the plateau diminished when the R-ratio was increased to equal 0.33; the plateau was not present in the data generated in a saturated air

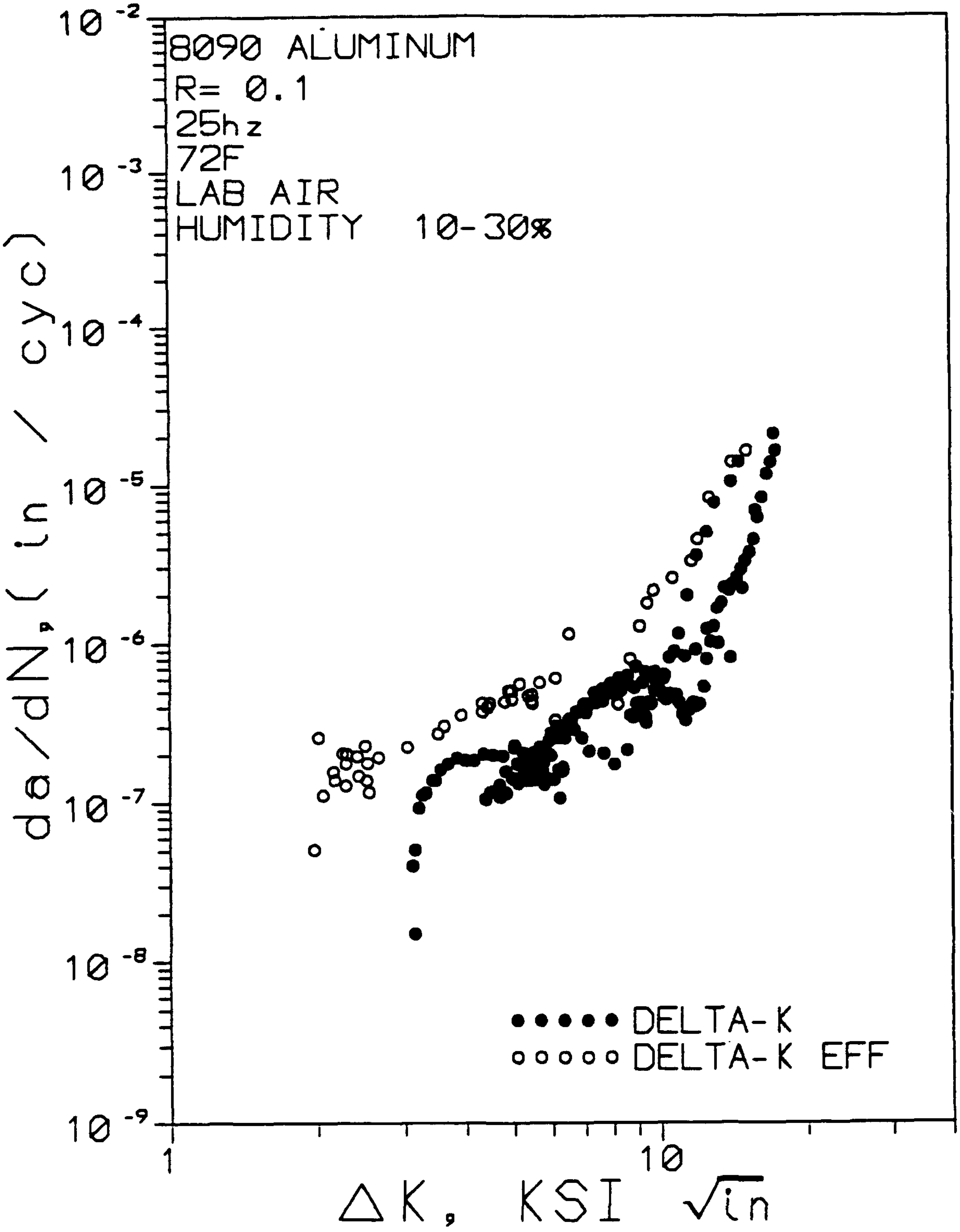


Figure 14. Fatigue crack growth rate test results for R=0.1 and a laboratory air environment.

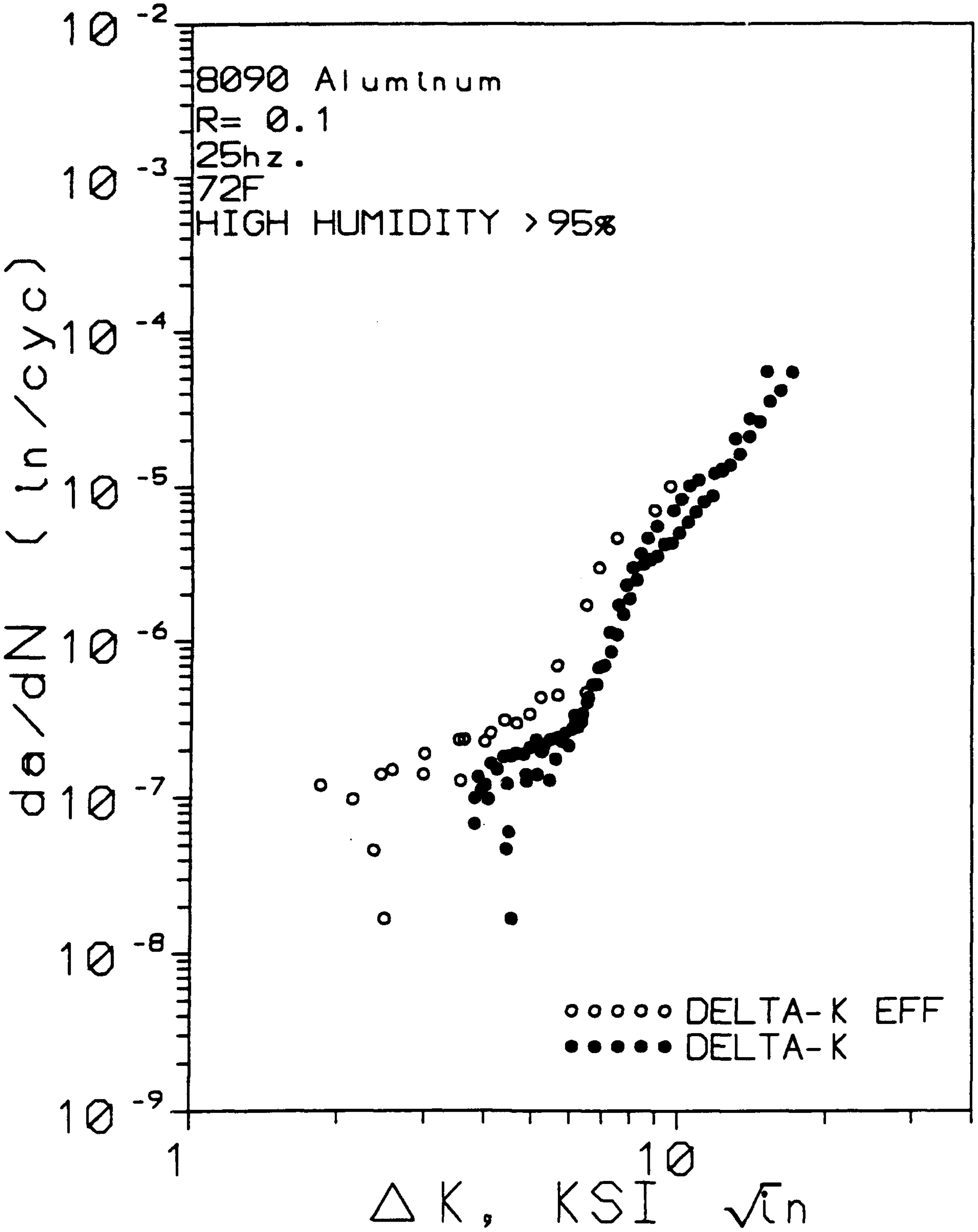


Figure 15. Fatigue crack growth rate test results for R=0.1 and a saturated air environment.

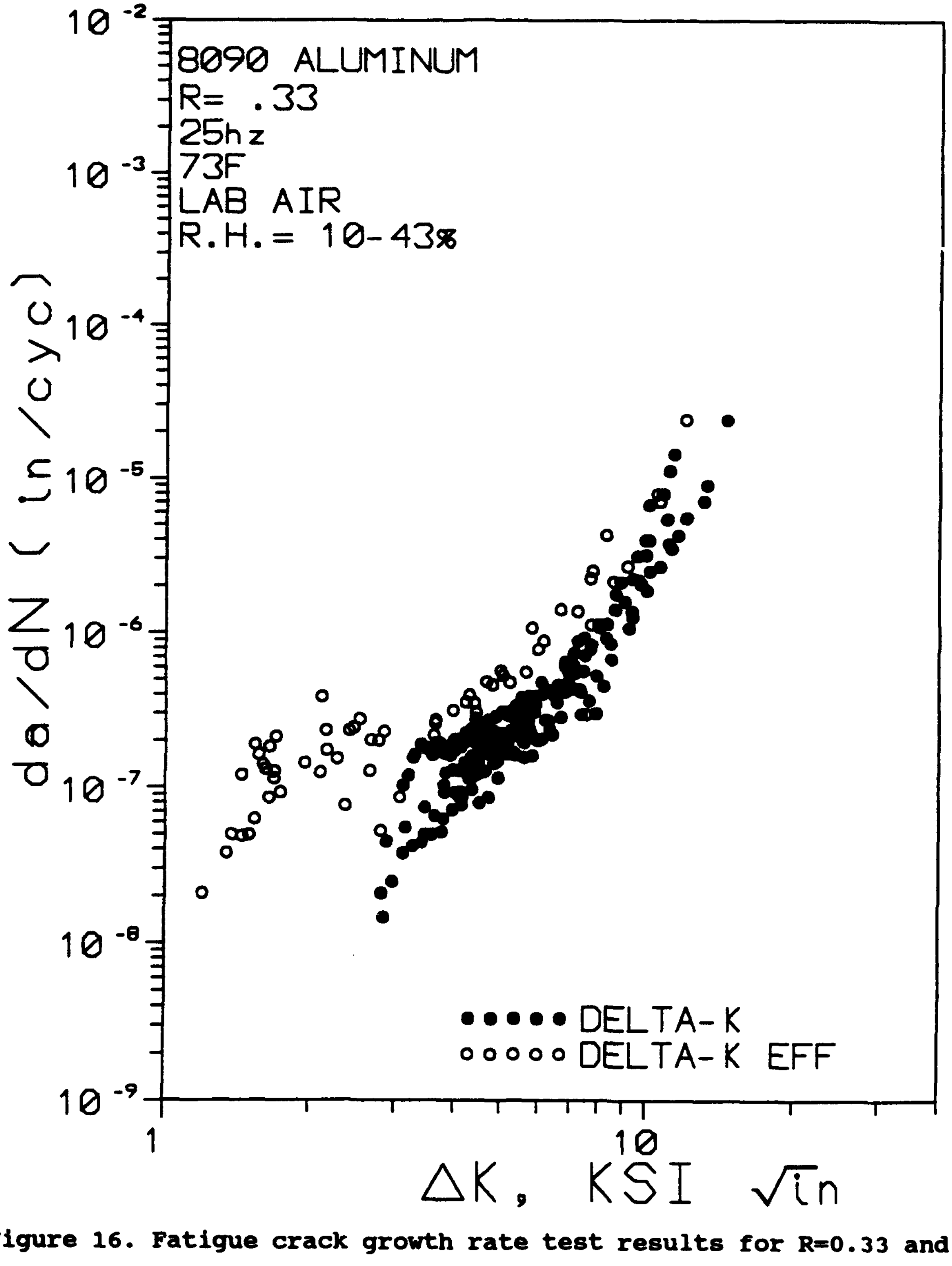


Figure 16. Fatigue crack growth rate test results for R=0.33 and a laboratory air environment.

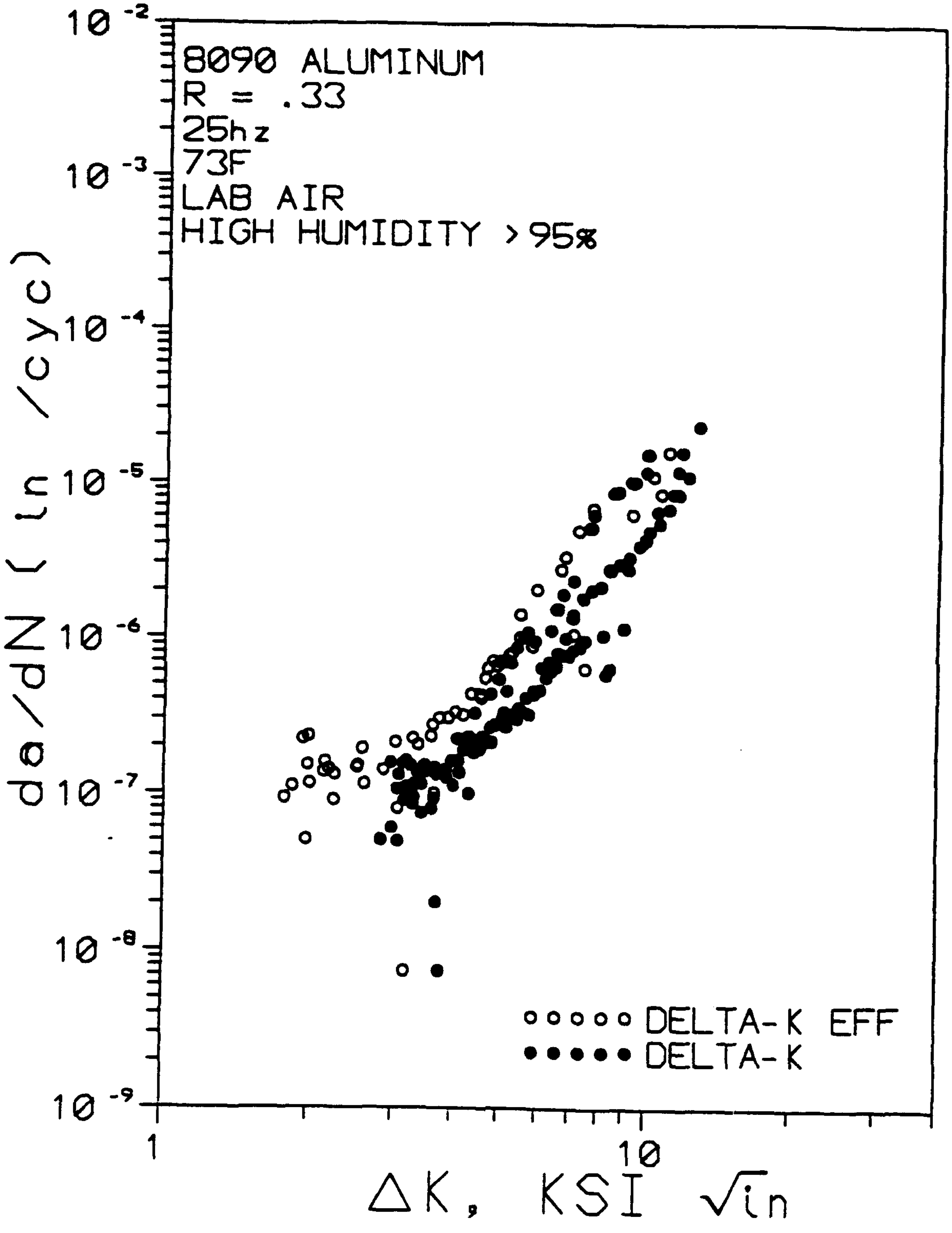


Figure 17. Fatigue crack growth rate test results for R=0.33 and a saturated air environment.

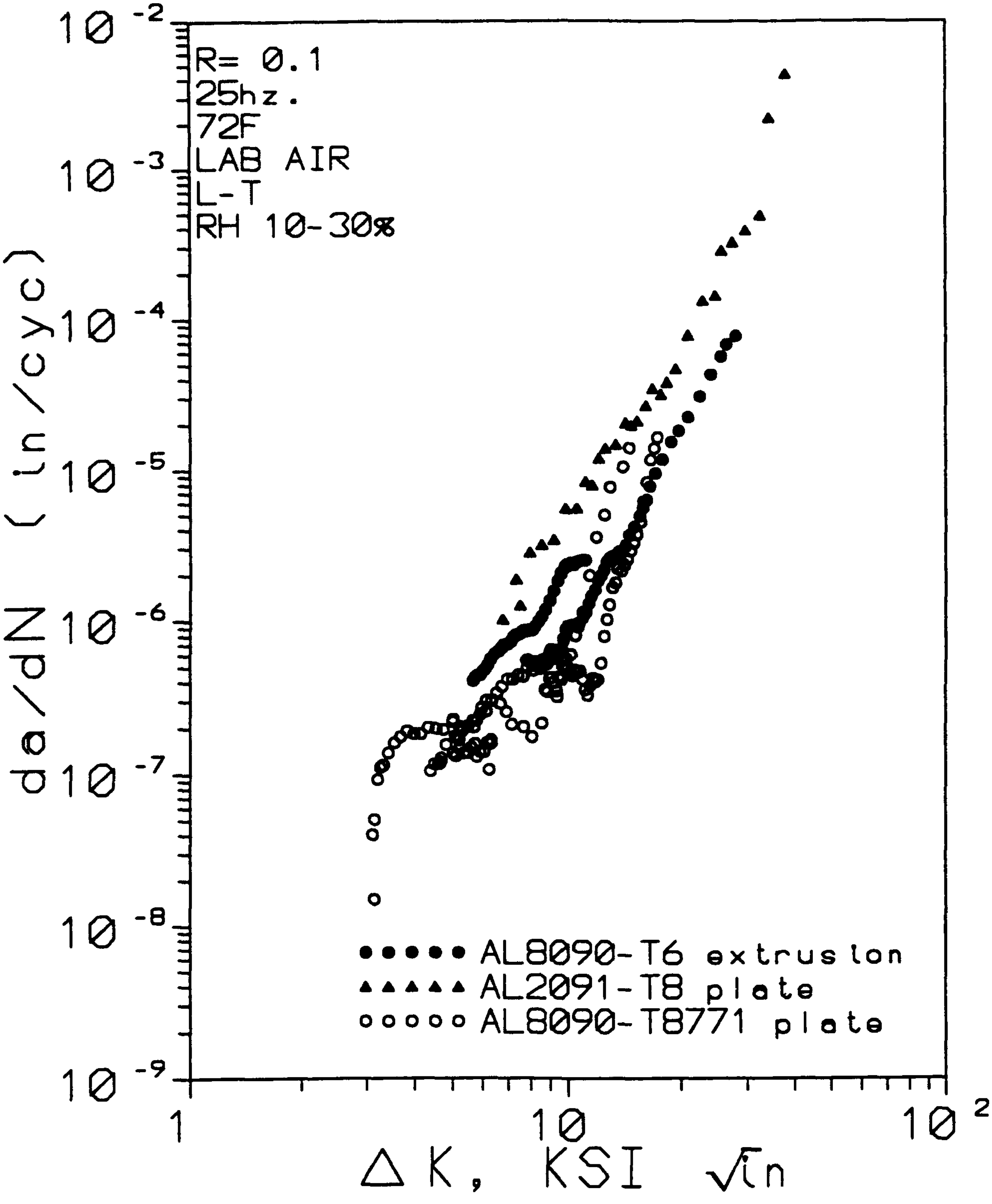


Figure 18. Laboratory air environment FCGR, R=0.1, data plotted along with Al-Li alloy Reference[30,31] data.

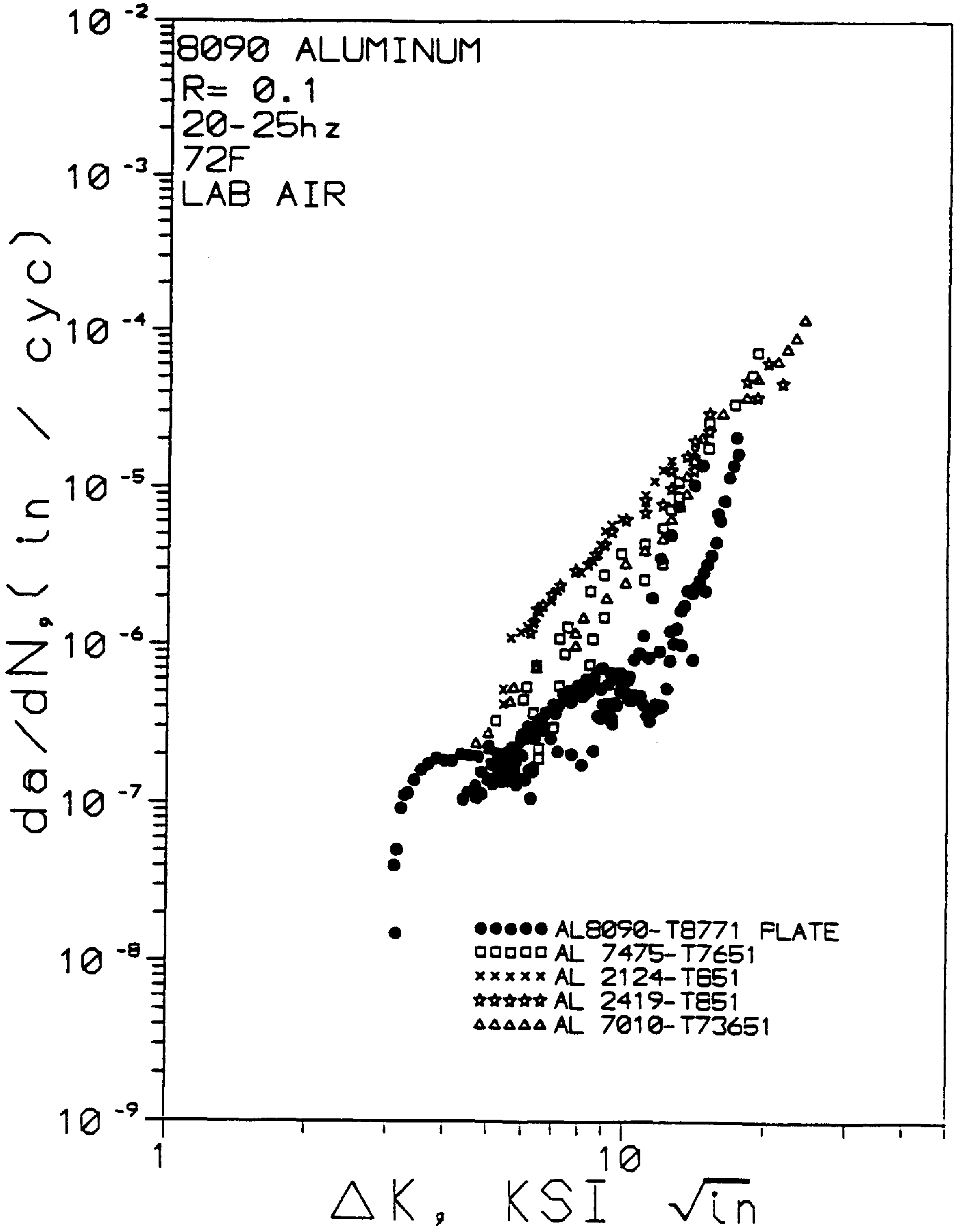


Figure 19. Laboratory air environment FCGR, R=0.1, data plotted along with conventional aluminum alloy Reference [33,35,38,40] data.

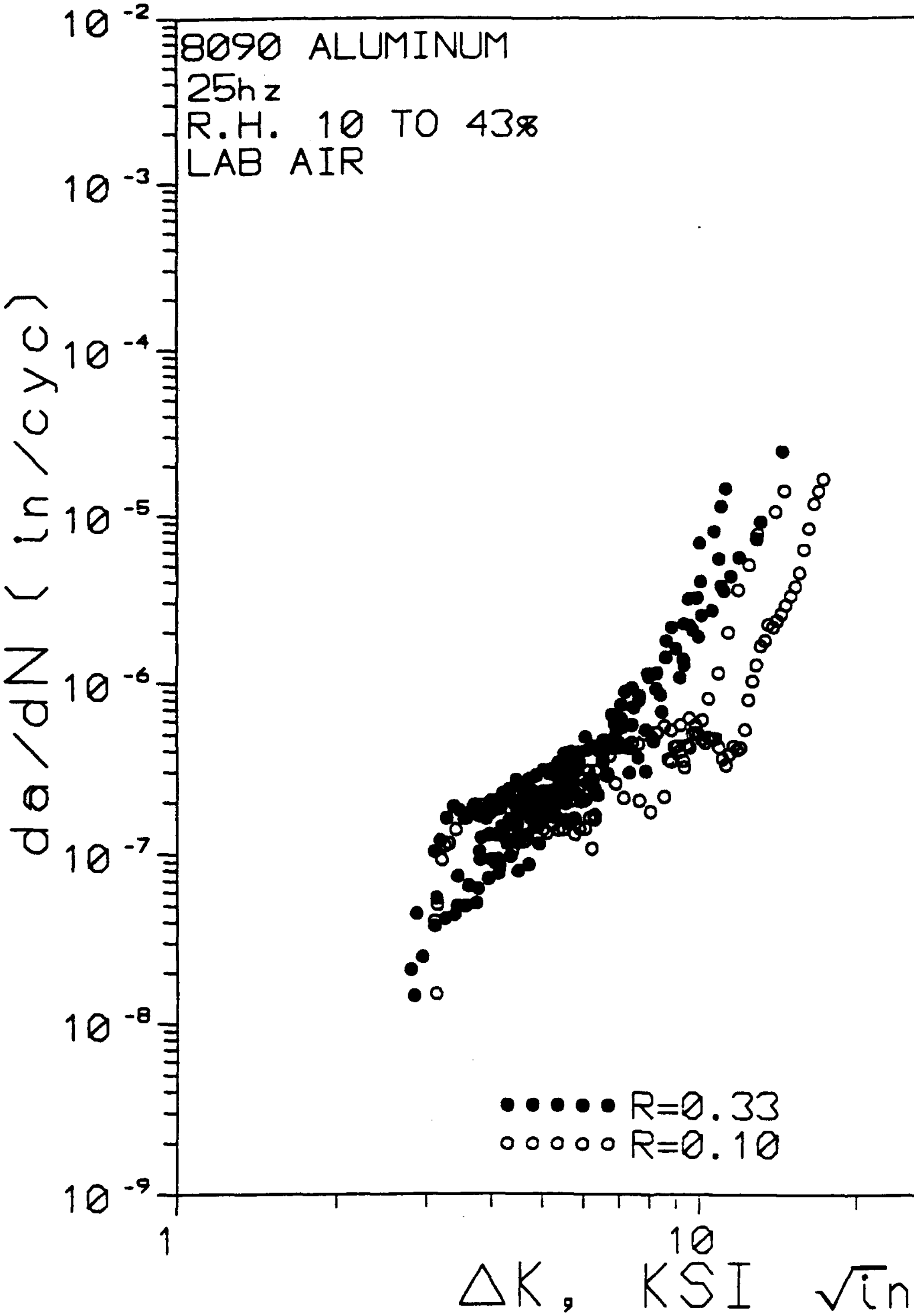


Figure 20. Laboratory air environment FCGR data for R-ratios of 0.1 and 0.33.

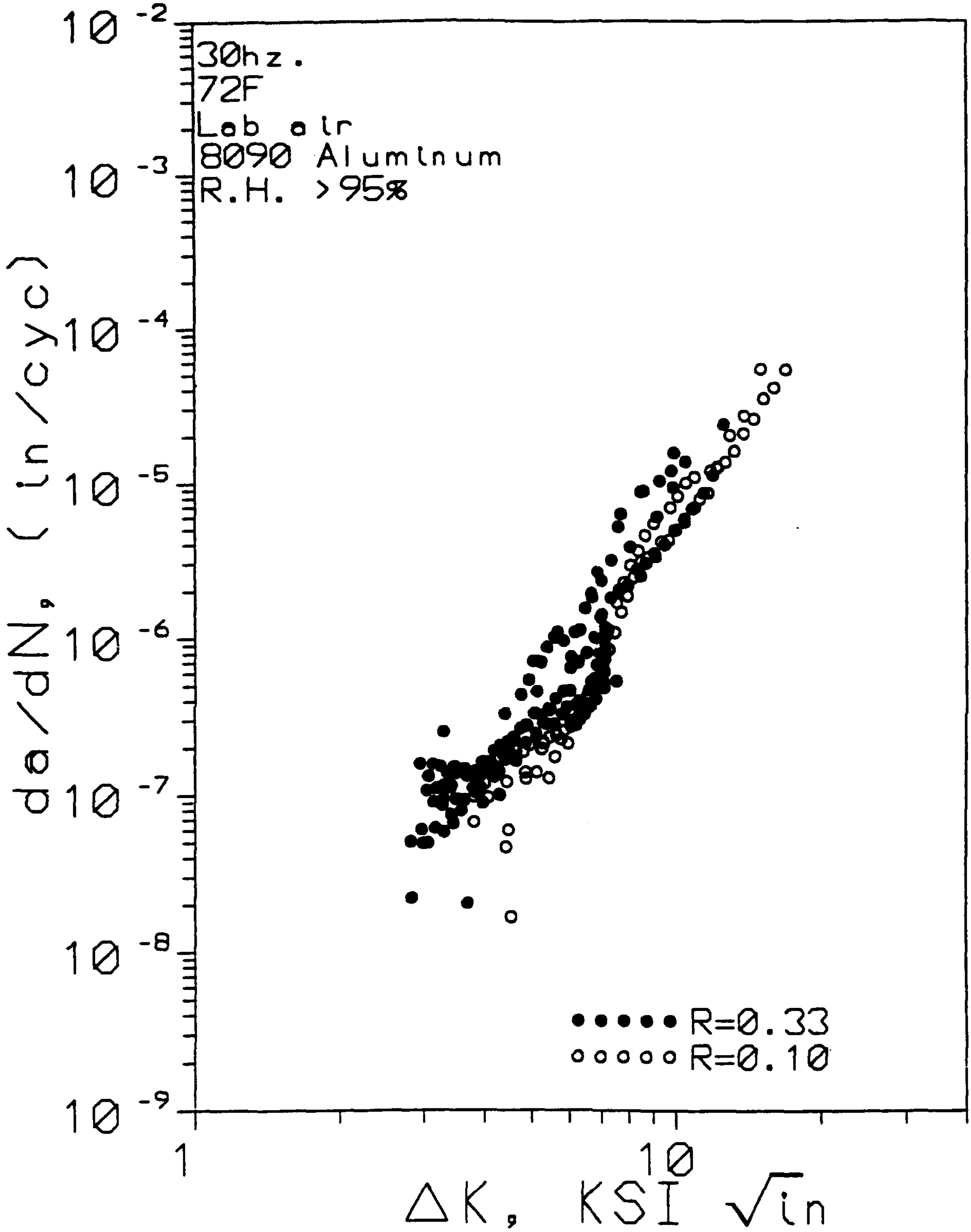


Figure 21. Saturated air environment FCGR data for R-ratios of 0.1 and 0.33.

environment. The test results for the two R-ratios plot in overlapping data scatter bands in both test environments. For both R-ratios, above near threshold region, the saturated air environment slightly accelerates the growth rate over that of the laboratory air environment.

Spectrum fatigue test results are presented in Figure 22 and 23. Figure 22 presents test results plus data for Al-Li alloy 2091-T351 plate[30] using the standard spectrum FALSTAFF along with a peak stress condition of 20 KSI. Figure 23 depicts our test material's results plus data for alloy 8090-T651 extrusion [31] both subjected to the standard spectrum MINI-TWIST and using a maximum loading condition equal to 17 KSI. In both cases, the life of the test material approximately doubled that of the reference Al-Li alloy extrusion and plate materials. Thus, the spectrum fatigue test results reinforce the observation made in the constant amplitude loading fatigue crack growth rate data discussion, the course unrecrystalized grain structure of the T8 thermal processing shows improved damage tolerance when compared to a recrystallized grain structure, Al-Li alloy products.

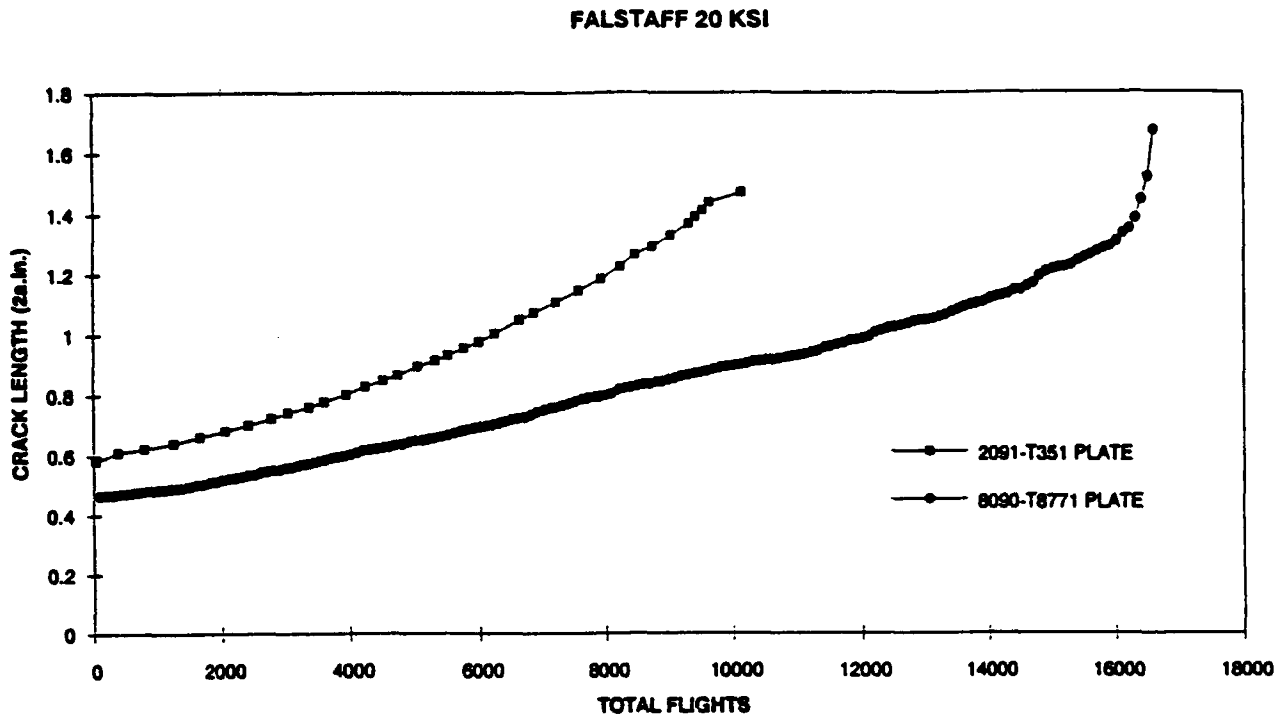


Figure 22. FALSTAFF Spectrum fatigue test results for the test material along with Al 2091-T351 plate Reference[30] data.

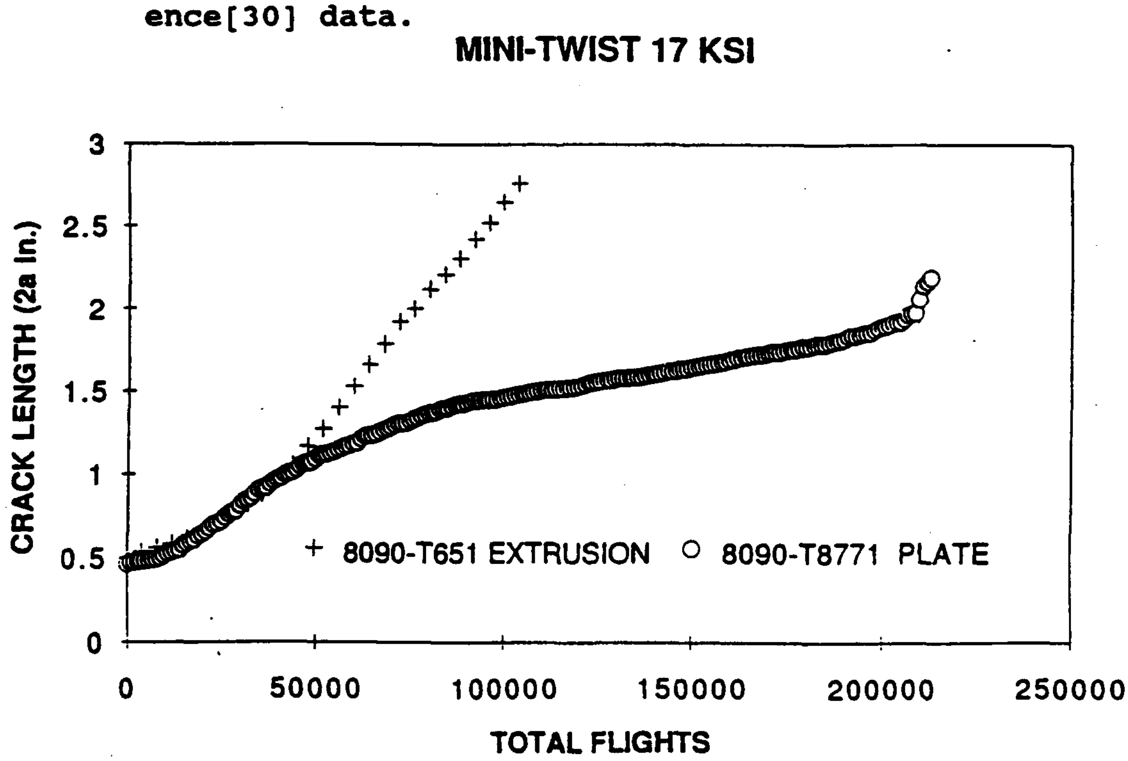


Figure 23. MINI-TWIST spectrum fatigue test results for the test material along with Al 8090-T651 extrusion Reference[31] data.

SECTION 4
CONCLUSIONS

1. Tensile, compression, bearing and shear strengths as well as fatigue properties are all good.

2. The lowest yield strength was found for specimens removed from the rolling plane, 45 degrees off the rolling direction.

3. For through-the-thickness ductility, the T8771 thermal processing represents an improvement over the more conventional T651 heat treatment. However, the through-the-thickness ductility, as indicated by the percent of permanent elongation, is still unacceptably low.

4. Fracture toughness for the L-T and T-L orientations were acceptable; for the through-the-thickness, S-L orientation, the fracture toughness was cut in half.

5. The test material's fracture toughness was comparable to many other Al-Li thick product forms. However, it was low, when compared to conventional aerospace aluminum products, especially, when loading through-the-thickness, S-L orientation.

6. Fatigue crack growth resistance was superior when compared to other Al-Li thick product forms or conventional aerospace aluminum products.

7. The material showed considerable surface roughness induced crack closure attributable to the mostly unrecrystallized grain structure.

8. The log-da/dN versus log-ΔK plot showed a plateau of nearly constant crack velocity over the normally linear mid-range for R=0.1 and with the relative humidity below 50 percent; the effect diminishes when the R-ratio was increased to 0.33. The plateau was not present for data generated in the saturated air environment.

9. Increasing the R-ratio from 0.1 to 0.33 accelerated the crack growth rate slightly.

10. Increasing the relative humidity from below 50 perecent to a saturated condition increased the crack velocity somewhat, above the near threshold region.

SECTION 5
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APPENDIX A

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D LT1
SPECIMEN WIDTH: 2.005
SPECIMEN THK.: .249

MAX. LOAD (LBS): 222
MIN. LOAD (LBS): 22
STRESS RATIO: 0.1
TEST FREQUENCY hz: 30
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: LAB AIR
TEST TEMPERATURE F: 73F
RELATIVE HUMIDITY: 10-30%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

'a (in)	kilocycles	'da/dN (in/cyc)	Del K (KSI-in ^ 0.5)
0.566	32.00	3.17E-07	6.52
0.576	77.70	2.21E-07	6.08
0.587	132.50	1.87E-07	5.71
0.597	191.60	1.71E-07	5.43
0.607	263.20	1.41E-07	5.10
0.617	325.60	1.64E-07	4.77
0.627	399.30	1.39E-07	4.47
0.637	478.50	1.28E-07	4.19
0.647	584.40	9.65E-08	3.92
0.658	695.80	9.08E-08	3.76
0.668	845.20	6.76E-08	3.52
0.678	1079.10	4.31E-08	3.32
0.688	1456.30	2.68E-08	3.10
0.710	2807.30	6.65E-08	3.62
0.730	2988.00	1.11E-07	3.69
0.750	3160.70	1.16E-07	3.79
0.770	3298.50	1.45E-07	3.89
0.790	3439.10	1.44E-07	3.98
0.810	3571.20	1.52E-07	4.09
0.830	3694.10	1.63E-07	4.19
0.850	3801.40	1.87E-07	4.30
0.871	3910.60	1.85E-07	4.42
0.891	4009.70	2.02E-07	4.54
0.911	4086.10	2.62E-07	4.65
0.931	4162.90	2.61E-07	4.78
0.951	4224.10	3.32E-07	4.89
0.971	4276.80	3.80E-07	5.06
0.991	4329.70	3.79E-07	5.19
1.011	4370.10	4.96E-07	5.33
1.031	4408.40	5.26E-07	5.46
1.051	4443.50	5.72E-07	5.62
1.072	4476.10	6.19E-07	5.98
1.092	4507.40	6.40E-07	6.12
1.112	4534.90	7.30E-07	6.29
1.132	4564.50	6.77E-07	6.42
1.152	4594.20	6.75E-07	6.79
1.172	4625.50	6.44E-07	6.94
1.192	4647.80	9.07E-07	7.13
1.212	4671.50	8.51E-07	7.64
1.233	4693.10	9.31E-07	7.88
1.253	4709.20	1.26E-06	8.08
1.273	4729.20	1.03E-06	8.53
1.293	4753.40	8.29E-07	8.84
1.314	4762.30	2.27E-06	9.43
1.334	4765.20	6.87E-06	9.76
1.368	4766.80	2.25E-05	9.99

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D LT1B
SPECIMEN WIDTH: 2.005
SPECIMEN THK.: .249

MAX. LOAD (LBS): 279
MIN. LOAD (LBS): 28
STRESS RATIO: 0.1
TEST FREQUENCY hz: 25
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: LAB AIR
TEST TEMPERATURE F: 77
RELATIVE HUMIDITY: 10-24%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

'a (in)	'cycles	'da/dN (in/cyc)	Del K (KSI-in ^0.5)
0.624	813245.00	1.37E-07	5.38
0.635	883170.00	1.47E-07	5.23
0.645	964643.00	1.32E-07	5.11
0.656	1040810.00	1.38E-07	5.03
0.676	1181650.00	1.56E-07	4.82
0.687	1268480.00	1.20E-07	4.66
0.697	1349320.00	1.28E-07	4.68
0.708	1439580.00	1.18E-07	4.61
0.718	1528700.00	1.16E-07	4.49
0.729	1630270.00	1.05E-07	4.39
0.782	1757230.00	2.28E-07	5.02
0.793	1816850.00	1.76E-07	5.08
0.803	1874390.00	1.78E-07	5.15
0.813	1934940.00	1.68E-07	5.21
0.834	2045030.00	1.93E-07	5.33
0.855	2143460.00	2.07E-07	5.51
0.875	2234040.00	2.23E-07	5.65
0.895	2324600.00	2.25E-07	5.79
0.915	2399060.00	2.71E-07	5.96
0.936	2466000.00	3.03E-07	6.13
0.956	2533690.00	3.03E-07	6.34
0.976	2592940.00	3.38E-07	6.53
0.997	2647500.00	3.72E-07	6.73
1.017	2696820.00	4.18E-07	6.97
1.037	2744830.00	4.17E-07	7.19
1.057	2790230.00	4.44E-07	7.42
1.077	2836180.00	4.36E-07	7.64
1.098	2876700.00	4.98E-07	7.84
1.118	2919090.00	4.75E-07	8.11
1.138	2958840.00	5.08E-07	8.30
1.158	2995420.00	5.56E-07	8.58
1.179	3033890.00	5.28E-07	8.84
1.199	3069170.00	5.68E-07	9.21
1.219	3101640.00	6.22E-07	9.59
1.239	3135130.00	6.06E-07	10.16
1.259	3160290.00	8.11E-07	10.45
1.279	3177720.00	1.15E-06	10.93
1.300	3187930.00	2.00E-06	11.41
1.320	3193550.00	3.57E-06	11.91
1.341	3197740.00	5.01E-06	12.50
1.362	3200540.00	7.69E-06	12.97
1.383	3202490.00	1.05E-05	14.02
1.404	3203970.00	1.40E-05	14.58

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D LT7
SPECIMEN WIDTH: 2.001
SPECIMEN THK.: .248

MAX. LOAD (LBS): 125
MIN. LOAD (LBS): 13
STRESS RATIO: 0.1
TEST FREQUENCY hz: 25
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: LAB AIR
TEST TEMPERATURE F: 73
RELATIVE HUMIDITY: 10-30%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

'a (in)	'cycles	'da/dN (in/cyc)	Del K (KSI-in ^ 0.5)
0.999	3644200.00	1.50E-08	3.14
1.015	8234510.00	4.01E-08	3.11
1.026	8439000.00	5.06E-08	3.15
1.036	8549570.00	9.26E-08	3.21
1.046	8643150.00	1.11E-07	3.26
1.057	8732380.00	1.15E-07	3.32
1.077	8878530.00	1.38E-07	3.42
1.097	9002890.00	1.61E-07	3.55
1.117	9116640.00	1.76E-07	3.68
1.137	9221700.00	1.91E-07	3.83
1.157	9333070.00	1.84E-07	3.99
1.178	9442920.00	1.83E-07	4.15
1.198	9545460.00	2.02E-07	4.34
1.218	9646890.00	1.98E-07	4.54
1.239	9750430.00	1.96E-07	4.75
1.259	9841340.00	2.20E-07	5.01
1.279	9939390.00	2.04E-07	5.23
1.299	10039400.00	2.01E-07	5.26
1.319	10137700.00	2.04E-07	5.48
1.339	10236400.00	2.03E-07	5.70
1.359	10317900.00	2.46E-07	5.91
1.379	10395500.00	2.58E-07	6.12
1.399	10464900.00	2.89E-07	6.67
1.419	10543500.00	2.55E-07	6.91
1.439	10639300.00	2.10E-07	7.15
1.459	10737900.00	2.03E-07	7.67
1.479	10852400.00	1.75E-07	8.06
1.499	10946400.00	2.14E-07	8.55
1.519	11009100.00	3.19E-07	9.37
1.539	11048700.00	5.10E-07	9.85

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D LT8
SPECIMEN WIDTH: 2.003
SPECIMEN THK.: .249

MAX. LOAD (LBS): 441
MIN. LOAD (LBS): 44
STRESS RATIO: 0.1
TEST FREQUENCY hz: 25
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: LAB AIR
TEST TEMPERATURE F: 72
RELATIVE HUMIDITY: 10-30%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

'a (in)	'cycles	'da/dN (in/cyc)	Del K (KSI-in^0.5)
0.849	312626.00	3.55E-07	8.72
0.859	342158.00	3.45E-07	8.83
0.869	366273.00	4.20E-07	8.95
0.879	389835.00	4.25E-07	9.07
0.889	415158.00	3.96E-07	9.19
0.899	444119.00	3.49E-07	9.33
0.910	468036.00	4.30E-07	9.46
0.920	492125.00	4.18E-07	9.59
0.930	512028.00	5.03E-07	9.72
0.940	529812.00	5.66E-07	9.86
0.950	549897.00	5.01E-07	10.00
0.960	571521.00	4.64E-07	10.15
0.970	594219.00	4.44E-07	10.30
0.980	615149.00	4.79E-07	10.46
0.990	636799.00	4.69E-07	10.61
1.000	658109.00	4.74E-07	10.77
1.011	682391.00	4.19E-07	10.94
1.021	710519.00	3.59E-07	11.12
1.031	741795.00	3.30E-07	11.28
1.041	768176.00	3.82E-07	11.47
1.051	791748.00	4.25E-07	11.68
1.061	816719.00	4.04E-07	11.85
1.071	840812.00	4.16E-07	12.03
1.081	859654.00	5.34E-07	12.27
1.091	872380.00	7.97E-07	12.46
1.101	882142.00	1.03E-06	12.69
1.112	889985.00	1.28E-06	12.89
1.122	896066.00	1.66E-06	13.14
1.132	901802.00	1.79E-06	13.38
1.142	906503.00	2.22E-06	13.58
1.152	911202.00	2.14E-06	13.88
1.163	915561.00	2.35E-06	14.12
1.173	919559.00	2.56E-06	14.39
1.183	923043.00	2.91E-06	14.68
1.193	926166.00	3.30E-06	14.97
1.204	928964.00	3.74E-06	15.28
1.214	931214.00	4.51E-06	15.57
1.225	932946.00	6.21E-06	15.89
1.236	934322.00	8.30E-06	16.23
1.248	935363.00	1.17E-05	16.60
1.260	936214.00	1.39E-05	16.96
1.271	936910.00	1.64E-05	17.32

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D LT4
SPECIMEN WIDTH: 2.004
SPECIMEN THK.: .250

MAX. LOAD (LBS): 329
MIN. LOAD (LBS): 33
STRESS RATIO: 0.1
TEST FREQUENCY hz: 5
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: HIGH HUMIDITY
TEST TEMPERATURE F: 70F
RELATIVE HUMIDITY: >95%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

'a (in)	'cycles	'da/dN (in/cyc)	Del K (KSI-in ^ 0.5)
0.806	790683.00	3.32E-07	6.13
0.816	827331.00	2.80E-07	6.21
0.836	893108.00	3.05E-07	6.34
0.856	943212.00	4.04E-07	6.51
0.876	981320.00	5.27E-07	6.69
0.896	1011050.00	6.78E-07	6.88
0.917	1040110.00	6.98E-07	7.07
0.937	1064010.00	8.52E-07	7.28
0.957	1082430.00	1.09E-06	7.50
0.978	1096220.00	1.48E-06	7.73
0.998	1106990.00	1.87E-06	7.97
1.018	1115150.00	2.47E-06	8.22
1.038	1121650.00	3.12E-06	8.49
1.058	1127710.00	3.31E-06	8.75
1.079	1133480.00	3.52E-06	9.05
1.099	1138400.00	4.18E-06	9.37
1.119	1143100.00	4.28E-06	9.70
1.139	1147140.00	4.98E-06	10.04
1.160	1150590.00	5.85E-06	10.44
1.180	1153600.00	6.82E-06	10.83
1.200	1156140.00	7.94E-06	11.26
1.220	1158450.00	8.67E-06	11.71
1.240	1160020.00	1.28E-05	12.20
1.261	1161490.00	1.37E-05	12.71
1.281	1162770.00	1.61E-05	13.28
1.302	1163760.00	2.11E-05	13.89
1.323	1164570.00	2.60E-05	14.57
1.344	1165150.00	3.52E-05	15.27
1.365	1165660.00	4.13E-05	16.05
1.386	1166060.00	5.42E-05	16.93

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D LT5
SPECIMEN WIDTH: 2.010
SPECIMEN THK.: .248

MAX. LOAD (LBS): 229
MIN. LOAD (LBS): 23
STRESS RATIO: 0.1
TEST FREQUENCY hz: 25
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: HIGH HUMIDITY
TEST TEMPERATURE F: 72F
RELATIVE HUMIDITY: >95%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

'a (in)	kilocycles	'da/dN (in/cyc)	Del K (KSI-in ^ 0.5)
0.800	189.10	1.95E-07	5.24
0.810	270.30	1.27E-07	4.87
0.820	698.50	2.15E-07	5.31
0.830	770.80	1.39E-07	4.86
0.840	853.80	1.21E-07	4.44
0.850	959.00	9.65E-08	4.06
0.860	1111.90	6.74E-08	3.80
0.880	2404.50	4.65E-08	4.42
0.890	2577.70	5.99E-08	4.47
0.910	3787.70	1.66E-08	4.53
0.940	4425.10	1.39E-07	5.13
0.960	4527.80	1.96E-07	5.26
0.987	4691.97	1.28E-07	5.44
1.007	4806.63	1.75E-07	5.60
1.027	4895.51	2.26E-07	5.77
1.047	4989.98	2.13E-07	5.96
1.067	5057.27	2.98E-07	6.15
1.087	5115.85	3.43E-07	6.37
1.107	5161.86	4.37E-07	6.56
1.128	5200.01	5.28E-07	6.82
1.148	5228.75	6.97E-07	7.02
1.168	5246.50	1.13E-06	7.25
1.188	5258.34	1.70E-06	7.56
1.208	5267.19	2.28E-06	7.83
1.229	5274.15	2.96E-06	8.08
1.249	5279.70	3.64E-06	8.39
1.270	5284.21	4.59E-06	8.67
1.290	5287.86	5.50E-06	9.04
1.311	5290.88	6.96E-06	9.77
1.332	5293.47	8.24E-06	10.12
1.353	5295.55	1.00E-05	10.53
1.374	5297.45	1.10E-05	10.98
1.396	5299.25	1.21E-05	11.83
1.416	5300.87	1.26E-05	12.23
1.437	5301.89	2.03E-05	13.00
1.462	5302.82	2.73E-05	13.91
1.498	5303.48	5.48E-05	15.05

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D LT6
SPECIMEN WIDTH: 2.004
SPECIMEN THK.: .249

MAX. LOAD (LBS): 185
MIN. LOAD (LBS): 19
STRESS RATIO: 0.1
TEST FREQUENCY hz: 25
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: HIGH HUMIDITY
TEST TEMPERATURE F: 73
RELATIVE HUMIDITY: >95%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

'a (in)	'cycles	'da/dN (in/cyc)	Del K (KSI-in ^ 0.5)
0.874	2325480.00	9.81E-08	3.80
0.884	2401640.00	1.35E-07	3.86
0.894	2493990.00	1.11E-07	3.92
0.914	2662840.00	1.19E-07	4.00
0.934	2786090.00	1.63E-07	4.11
0.954	2921420.00	1.49E-07	4.23
0.975	3033050.00	1.80E-07	4.37
0.995	3143440.00	1.83E-07	4.51
1.015	3251920.00	1.91E-07	4.64
1.036	3359010.00	1.89E-07	4.81
1.056	3455640.00	2.07E-07	4.95
1.076	3541980.00	2.32E-07	5.11
1.096	3636350.00	2.13E-07	5.29
1.116	3721840.00	2.34E-07	5.47
1.136	3804890.00	2.41E-07	5.65
1.156	3883770.00	2.57E-07	5.86
1.176	3957210.00	2.72E-07	6.06
1.196	4022470.00	3.07E-07	6.27
1.216	4084250.00	3.24E-07	6.49
1.236	4143040.00	3.40E-07	6.73
1.256	4207380.00	3.11E-07	7.00
1.276	4252110.00	4.50E-07	7.26
1.296	4297270.00	4.45E-07	7.56
1.317	4340700.00	4.68E-07	7.85
1.337	4380220.00	5.06E-07	8.49
1.357	4420350.00	4.99E-07	8.78
1.377	4462380.00	4.80E-07	9.10
1.397	4512160.00	4.03E-07	9.75
1.417	4561480.00	4.08E-07	9.99
1.437	4598510.00	5.49E-07	10.69
1.457	4622110.00	8.49E-07	11.37
1.477	4634380.00	1.63E-06	12.09
1.498	4642470.00	2.54E-06	13.00
1.519	4647200.00	4.35E-06	13.83

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D.: LT9
SPECIMEN WIDTH: 2.006
SPECIMEN THK.: .249

MAX. LOAD (LBS): 245
MIN. LOAD (LBS): 81
STRESS RATIO: 0.33
TEST FREQUENCY hz: 25
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: LAB AIR
TEST TEMPERATURE F: 73F
RELATIVE HUMIDITY: 10-30%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

a(in)	cycles	da/dn (in/cyc)	DEL-K(ksi-in^0.5)
0.813	527153	9.24E-08	3.80
0.823	664586	7.42E-08	3.45
0.834	852471	5.50E-08	3.14
0.844	1078130	4.47E-08	2.87
0.884	1466050	1.87E-07	3.74
0.894	1526610	1.65E-07	3.79
0.914	1640110	1.76E-07	3.86
0.934	1756580	1.72E-07	3.98
0.954	1866590	1.82E-07	4.10
0.974	1967690	1.99E-07	4.22
0.994	2064080	2.08E-07	4.35
1.014	2164830	1.99E-07	4.48
1.034	2257210	2.18E-07	4.61
1.054	2344170	2.31E-07	4.76

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D.: LT10
SPECIMEN WIDTH: 2.005
SPECIMEN THK.: .249

MAX. LOAD (LBS): 272
MIN. LOAD (LBS): 90
STRESS RATIO: 0.33
TEST FREQUENCY hz: 25
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: LAB AIR
TEST TEMPERATURE F: 73
RELATIVE HUMIDITY: 10-30%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

a(in)	cycles	da/dn (in/cyc)	DEL-K(ksi-in^0.5)
0.762	21016	4.97E-07	6.36
0.772	54783	3.06E-07	5.83
0.782	96761	2.47E-07	5.35
0.792	150417	1.89E-07	4.88
0.802	220199	1.45E-07	4.46
0.813	294405	1.43E-07	4.18
0.823	394193	1.03E-07	3.79
0.837	483340	1.77E-07	3.86
0.843	517184	1.60E-07	3.90
0.863	617339	2.03E-07	3.97
0.883	715910	2.03E-07	4.08
0.903	806102	2.24E-07	4.20
0.923	890690	2.37E-07	4.32
0.944	967609	2.68E-07	4.45
0.964	1053090	2.37E-07	4.59
0.984	1126860	2.73E-07	4.72
1.004	1197720	2.85E-07	4.86
1.024	1263480	3.05E-07	5.01
1.045	1329600	3.08E-07	5.18
1.065	1389430	3.37E-07	5.35
1.085	1442140	3.82E-07	5.51
1.105	1493790	3.89E-07	5.68
1.125	1545450	3.90E-07	5.89
1.145	1595160	4.04E-07	6.10
1.165	1642650	4.22E-07	6.31
1.186	1689930	4.26E-07	6.54
1.206	1738280	4.14E-07	6.79
1.226	1784360	4.36E-07	7.05
1.246	1832890	4.12E-07	7.32
1.266	1888360	3.63E-07	7.61
1.286	1955050	3.00E-07	7.88
1.306	1999360	4.53E-07	8.16
1.326	2029190	6.75E-07	8.47
1.347	2045290	1.27E-06	9.34
1.367	2054550	2.19E-06	9.61
1.387	2060980	3.20E-06	9.91
1.409	2064910	5.47E-06	10.94
1.431	2066450	1.45E-05	11.27

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D.: LT25
SPECIMEN WIDTH: 2.002
SPECIMEN THK.: .249

MAX. LOAD (LBS): 155
MIN. LOAD (LBS): 51
STRESS RATIO: 0.33
TEST FREQUENCY hz: 25
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: LAB AIR
TEST TEMPERATURE F: 70F
RELATIVE HUMIDITY: 30-36%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

a(in)	cycles	da/dn (in/cyc)	DEL-K(ksi-in^0.5)
0.618	237329	2.71E-07	6.17
0.627	280085	2.05E-07	6.06
0.638	331659	2.02E-07	5.94
0.646	382319	1.60E-07	5.79
0.655	421616	2.41E-07	5.70
0.663	463466	1.96E-07	5.56
0.673	499762	2.76E-07	5.68
0.682	555289	1.56E-07	5.56
0.690	590631	2.29E-07	5.46
0.698	641827	1.62E-07	5.33
0.708	685082	2.32E-07	5.23
0.716	736481	1.64E-07	5.12
0.727	795018	1.73E-07	5.02
0.735	853382	1.48E-07	4.90
0.744	914527	1.43E-07	4.83
0.752	967034	1.62E-07	4.73
0.761	1034050	1.26E-07	4.62
0.770	1085800	1.77E-07	4.56
0.780	1138850	1.82E-07	4.47
0.788	1207580	1.17E-07	4.36
0.796	1278350	1.14E-07	4.28
0.806	1353870	1.35E-07	4.21
0.814	1445800	9.27E-08	4.11
0.822	1533590	9.22E-08	4.00
0.910	1776400	1.77E-07	4.87
0.932	1882440	2.00E-07	4.97
0.953	1954110	2.90E-07	5.17
0.973	2047900	2.17E-07	5.34
0.995	2112180	3.51E-07	5.52
1.016	2177430	3.07E-07	5.69
1.036	2230760	3.80E-07	5.86
1.056	2273120	4.78E-07	6.05
1.117	2385390	5.70E-07	6.88
1.138	2418310	6.14E-07	7.07
1.158	2466180	4.26E-07	7.29
1.179	2537930	2.95E-07	7.33
1.200	2577750	5.24E-07	7.90
1.221	2596560	1.13E-06	7.97
1.242	2608040	1.77E-06	8.64
1.264	2618410	2.13E-06	8.85
1.284	2624890	3.14E-06	9.53
1.304	2629920	3.98E-06	10.06
1.324	2632940	6.76E-06	10.04
1.345	2635480	7.96E-06	10.70
1.366	2637420	1.13E-05	11.04

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D LT28
SPECIMEN WIDTH: 2.003
SPECIMEN THK.: .248

MAX.LOAD(LBS): 289
MIN. LOAD (LBS): 95
STRESS RATIO: 0.33
TEST FREQUENCY hz: 15
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: LAB AIR
TEST TEMPERATURE F: 74
RELATIVE HUMIDITY: 36-44%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

'a (in)	'cycles	'da/dN (in/cyc)	Del K (KSI-in ^ 0.5)
0.651	1081720.00	7.74E-08	4.13
0.672	1487480.00	5.17E-08	3.74
0.683	1703550.00	4.97E-08	3.57
0.693	1932910.00	4.43E-08	3.40
0.894	3297950.00	1.57E-07	4.33
0.914	3429750.00	1.52E-07	4.46
0.935	3544860.00	1.80E-07	4.60
0.956	3655400.00	1.92E-07	4.74
0.977	3754060.00	2.10E-07	4.90
1.018	3923630.00	2.22E-07	5.22
1.038	3989040.00	3.13E-07	5.36
1.058	4051680.00	3.22E-07	5.53
1.078	4108720.00	3.55E-07	5.70
1.099	4168270.00	3.44E-07	5.88
1.119	4219330.00	3.95E-07	6.43
1.139	4264410.00	4.44E-07	6.65
1.159	4306060.00	4.82E-07	6.89
1.179	4342560.00	5.50E-07	7.11
1.199	4378020.00	5.66E-07	7.41
1.220	4402510.00	8.35E-07	7.68
1.240	4421030.00	1.08E-06	7.99
1.260	4438650.00	1.14E-06	8.28
1.281	4453290.00	1.41E-06	8.61
1.301	4466100.00	1.59E-06	9.00
1.321	4475020.00	2.25E-06	9.35
1.341	4484810.00	2.07E-06	9.72
1.362	4493080.00	2.50E-06	10.12
1.383	4498580.00	3.76E-06	11.04
1.403	4503380.00	4.29E-06	11.52
1.423	4507010.00	5.56E-06	11.96
1.444	4509900.00	7.16E-06	12.94
1.466	4512350.00	9.10E-06	13.13
1.489	4513300.00	2.41E-05	14.43

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D.: LT29
SPECIMEN WIDTH: 2.003
SPECIMEN THK.: .248

MAX. LOAD (LBS): 229
MIN. LOAD (LBS): 76
STRESS RATIO: 0.33
TEST FREQUENCY hz: 25
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: LAB AIR
TEST TEMPERATURE F: 74
RELATIVE HUMIDITY: 37-43%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

a(in)	cycles	da/dn (in/cyc)	DEL-K(ksi-in^0.5)
0.643	860418	9.67E-08	4.34
0.653	982041	8.55E-08	4.14
0.663	1124370	7.17E-08	3.95
0.674	1288800	6.26E-08	3.77
0.684	1452860	6.50E-08	3.62
0.695	1669820	4.97E-08	3.44
0.705	1918470	4.18E-08	3.26
0.717	2219630	3.77E-08	3.11
0.727	2652580	2.47E-08	2.95
0.740	3282370	2.08E-08	2.80
0.751	4000590	1.45E-08	2.84
0.798	4412480	1.03E-07	3.11
0.819	4584880	1.20E-07	3.19
0.840	4714420	1.62E-07	3.28
0.860	4822460	1.89E-07	3.38
0.880	4935190	1.78E-07	3.48
0.900	5061790	1.62E-07	3.58
0.921	5170240	1.93E-07	3.70
0.942	5334100	1.23E-07	3.82
0.962	5494650	1.29E-07	3.95
0.983	5653490	1.28E-07	4.08
1.003	5816160	1.23E-07	4.22
1.023	5949280	1.55E-07	4.36
1.045	6068340	1.78E-07	4.50
1.065	6188600	1.69E-07	4.61
1.085	6291840	1.94E-07	4.74
1.105	6383170	2.21E-07	4.87
1.126	6477860	2.20E-07	5.00
1.146	6579540	1.98E-07	5.14
1.166	6651560	2.82E-07	5.30
1.187	6725050	2.77E-07	5.48
1.207	6802650	2.58E-07	5.63
1.227	6861400	3.50E-07	5.82
1.247	6909500	4.19E-07	6.36
1.268	6953540	4.59E-07	6.56
1.288	7002360	4.24E-07	6.72
1.309	7040850	5.30E-07	6.93
1.32[illegible]	7069090	7.16E-07	7.47
1.349	7094660	7.85E-07	7.65
1.370	7116850	9.23E-07	8.26
1.390	7140730	8.51E-07	8.42
1.410	7159440	1.08E-06	9.19
1.431	7174540	1.37E-06	9.31
1.451	7185380	1.88E-06	9.97
1.472	7193010	2.70E-06	10.61
1.492	7198750	3.52E-06	11.17

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.C LT22
SPECIMEN WIDTH: 2.004
SPECIMEN THK.: .249

MAX. LOAD (LBS): 272
MIN. LOAD (LBS): 90
STRESS RATIO: 0.33
TEST FREQUENCY hz: 25
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: HIGH HUMIDITY
TEST TEMPERATURE F: 74F
RELATIVE HUMIDITY: >95%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

'a (in)	'cycles	'da/dN (in/cyc)	Del K (KSI-in ^ 0.5)
0.624	587606.00	- 1.32E-07	3.67
0.635	655018.00	1.52E-07	3.47
0.645	764572.00	9.45E-08	3.28
0.655	876940.00	9.05E-08	3.13
0.665	1045260.00	6.03E-08	2.96
0.676	1247030.00	5.05E-08	2.81
0.696	1489780.00	1.58E-07	2.94
0.707	1587050.00	1.07E-07	3.03
0.728	1750380.00	1.32E-07	3.06
0.749	1881240.00	1.56E-07	3.13
0.770	2017860.00	1.52E-07	3.24
0.795	2118810.00	2.53E-07	3.29
0.816	2302430.00	1.15E-07	3.41
0.837	2449330.00	1.38E-07	3.49
0.857	2701100.00	8.06E-08	3.58
0.877	3701900.00	2.04E-08	3.68
0.931	10260964.00	1.00E-07	4.29
0.952	10323486.00	3.29E-07	4.41
0.972	10371096.00	4.35E-07	4.75
0.993	10408858.00	5.39E-07	4.94
1.013	10437386.00	7.14E-07	5.04
1.033	10466108.00	7.05E-07	5.18
1.054	10495776.00	6.96E-07	5.24
1.075	10519765.00	8.72E-07	5.39
1.095	10539603.00	1.01E-06	5.58
1.116	10558491.00	1.09E-06	5.67
1.136	10579658.00	9.61E-07	5.84
1.156	10597875.00	1.13E-06	6.33
1.177	10611108.00	1.55E-06	6.48
1.197	10621673.00	1.92E-06	6.68
1.218	10636672.00	1.36E-06	6.99
1.238	10645349.00	2.35E-06	7.02
1.259	10649377.00	5.22E-06	7.61
1.279	10652569.00	6.32E-06	7.69
1.300	10654695.00	8.78E-06	8.48
1.322	10657342.00	8.93E-06	8.59
1.342	10659344.00	1.04E-05	9.29
1.364	10661119.00	1.21E-05	9.80
1.384	10662419.00	1.57E-05	9.93

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D LT23
SPECIMEN WIDTH: 2.004
SPECIMEN THK.: .249

MAX. LOAD (LBS): 359
MIN. LOAD (LBS): 119
STRESS RATIO: 0.33
TEST FREQUENCY hz: 25
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: HIGH HUMIDITY
TEST TEMPERATURE F: 74
RELATIVE HUMIDITY: >95%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

'a (in)	'cycles	'da/dN (in/cyc)	Del K (KSI-in ^0.5)
0.6224	1955155.00	1.13E-07	3.98
0.6330	2002525.00	2.25E-07	4.05
0.6438	2050867.00	2.23E-07	4.10
0.6839	2228793.00	2.32E-07	4.28
0.7040	2320017.00	2.21E-07	4.39
0.7240	2423159.00	1.94E-07	4.52
0.7446	2518379.00	2.16E-07	4.66
0.7647	2612657.00	2.13E-07	4.77
0.7850	2691799.00	2.56E-07	4.89
0.8053	2757939.00	3.06E-07	5.04
0.8255	2833697.00	2.67E-07	5.12
0.8459	2900199.00	3.08E-07	5.27
0.8660	2967081.00	3.00E-07	5.39
0.8864	3028312.00	3.34E-07	5.52
0.9067	3091043.00	3.23E-07	5.70
0.9274	3138365.00	4.38E-07	5.82
0.9480	3182569.00	4.65E-07	5.99
0.9688	3219971.00	5.56E-07	6.17
0.9891	3252842.00	6.17E-07	6.31
1.0096	3283629.00	6.61E-07	6.48
1.0299	3309696.00	7.85E-07	6.65
1.0511	3337103.00	7.74E-07	6.89
1.0712	3361106.00	8.39E-07	7.01
1.0917	3384161.00	8.89E-07	7.25
1.1110	3404762.00	9.75E-07	7.42
1.1322	3423930.00	1.06E-06	8.09
1.1526	3458141.00	5.92E-07	8.19
1.1727	3489681.00	6.43E-07	8.33
1.1931	3501460.00	1.17E-06	8.91
1.2144	3508995.00	2.82E-06	9.06
1.2355	3513781.00	4.40E-06	9.79
1.2558	3516965.00	1.34E+01	10.11
1.2771	3520157.00	6.67E-06	10.37
1.2989	3522669.00	8.70E-06	11.17
1.3217	3524544.00	1.22E-05	11.42
1.3429	3525840.00	1.63E-05	11.66

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 8.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D.: LT24
SPECIMEN WIDTH: 2.002
SPECIMEN THK.: .249

MAX. LOAD (LBS): 168
MIN. LOAD (LBS): 55
STRESS RATIO: 0.33
TEST FREQUENCY hz: 25
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: HIGH HUMIDUTY
TEST TEMPERATURE F: 74
RELATIVE HUMIDITY: >95%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

a(in)	cycles	da/dn (in/cyc)	DEL-K(ksi-in ^ 0.5)
0.621	160485	5.26E-07	7.06
0.631	180968	4.93E-07	6.94
0.641	206715	4.15E-07	6.82
0.651	234567	3.65E-07	6.63
0.662	266552	3.29E-07	6.48
0.672	297239	3.33E-07	6.34
0.682	324228	3.77E-07	6.18
0.692	350000	3.97E-07	6.27
0.715	397521	6.70E-07	6.87
0.725	410834	7.99E-07	6.96
0.736	430759	5.51E-07	6.80
0.747	454074	4.68E-07	6.61
0.757	484206	3.36E-07	6.48
0.767	516778	3.16E-07	6.34
0.777	552378	2.83E-07	6.20
0.787	587207	2.91E-07	6.05
0.798	615641	3.61E-07	5.92
0.818	677718	3.26E-07	5.81
0.838	748670	2.83E-07	5.59
0.858	819259	2.85E-07	5.31
0.879	903283	2.44E-07	5.11
0.899	998209	2.14E-07	4.86
0.919	1120570	1.64E-07	4.65
0.940	1248200	1.68E-07	4.42
0.961	1409590	1.30E-07	4.18
0.981	1551300	1.42E-07	4.26
1.002	1697520	1.40E-07	4.09
1.0218	1846510	1.35E-07	3.93
1.0418	2026480	1.11E-07	3.78
1.0626	2253970	9.14E-08	3.61
1.0826	2556780	6.62E-08	3.44
1.1028	2904160	5.82E-08	3.29
1.1229	3230650	6.16E-08	3.16
1.1432	3641090	4.93E-08	2.98
1.1634	4560560	2.21E-08	2.82
1.2002	10915926	1.14E-07	3.29
1.2107	11010212	1.11E-07	3.39
1.2206	11116948	9.41E-08	3.49
1.2412	11315597	1.03E-07	3.85
1.2612	11493833	1.12E-07	3.90
1.2813	11718934	8.92E-08	3.96
1.3227	15611000	2.83E-07	5.37
1.3426	15668613	3.49E-07	5.47
1.3629	15712213	4.62E-07	6.02
1.3834	15739306	7.58E-07	6.05
1.4035	15757666	1.09E-06	6.17
1.4238	15768802	1.83E-06	6.70
1.4457	15777037	2.65E-06	6.89
1.4662	15783497	3.18E-06	7.35
1.4867	15788807	3.87E-06	8.07
1.508	15797219	2.52E-06	8.49
1.5295	15800765	6.08E-06	9.16
1.5508	15803035	9.37E-06	9.90
1.5711	15804513	1.38E-05	10.48

MATERIAL: ALUMINUM
ALLOY: 8090
CONDITION/HT: T8771
FORM: 1.75 IN. PLATE
.2% YIELD STRENGTH (KSI): 68
ULT. STRENGTH (KSI): 77
MODULUS: 11.0
SPECIMEN TYPE: CT
ORIENTATION: L-T
SPECIMEN I.D LT27
SPECIMEN WIDTH: 2.004
SPECIMEN THK.: .248

MAX.LOAD(LBS): 249
MIN. LOAD (LBS): 82
STRESS RATIO: 0.33
TEST FREQUENCY hz: 15
CYCLIC WAVE FORM: SINE
TEST PROCEDURE: K-INCREASING
ENVIRONMENT: HIGH HUMIDITY
TEST TEMPERATURE F: 76
RELATIVE HUMIDITY: >95%
MEASUREMENT INTERVAL (IN.): .020
CRACK MEASUREMENT METHOD: COMPLIANCE

'a (in)	'cycles	'da/dN (in/cyc)	Del K (KSI-in ^ 0.5)
0.624	132833.00	2.79E-07	4.87
0.634	177724.00	2.26E-07	4.60
0.644	232883.00	1.83E-07	4.40
0.655	313581.00	1.37E-07	4.11
0.666	397311.00	1.27E-07	3.85
0.676	508427.00	9.35E-08	3.62
0.686	641947.00	7.51E-08	3.41
0.696	760663.00	8.59E-08	3.27
0.707	983856.00	4.98E-08	3.05
0.729	1320890.00	1.11E-07	3.17
0.739	1414070.00	1.11E-07	3.21
0.750	1514790.00	1.09E-07	3.25
0.760	1601580.00	1.15E-07	3.30
0.780	1748260.00	1.37E-07	3.35
0.800	1889030.00	1.43E-07	3.44
0.821	2034240.00	1.42E-07	3.54
0.842	2179440.00	1.46E-07	3.64
0.862	2325920.00	1.38E-07	3.75
0.882	2467230.00	1.42E-07	3.84
0.902	2590830.00	1.62E-07	3.95
0.923	2714700.00	1.63E-07	4.08
0.943	2819900.00	1.91E-07	4.18
0.963	2918330.00	2.06E-07	4.31
0.983	3012330.00	2.17E-07	4.45
1.004	3101480.00	2.34E-07	4.59
1.026	3181830.00	2.67E-07	4.75
1.046	3254410.00	2.76E-07	4.90
1.066	3315480.00	3.30E-07	5.07
1.086	3378050.00	3.21E-07	5.24
1.106	3436150.00	3.52E-07	5.42
1.127	3485720.00	4.13E-07	5.61
1.147	3530230.00	4.58E-07	5.82
1.168	3562070.00	6.47E-07	6.04
1.188	3591080.00	7.04E-07	6.28
1.208	3616030.00	8.06E-07	6.53
1.228	3635920.00	1.01E-06	6.79
1.249	3650250.00	1.42E-06	7.03
1.269	3661430.00	1.83E-06	7.34
1.290	3671310.00	2.06E-06	7.64
1.310	3680800.00	2.18E-06	7.98
1.331	3688050.00	2.79E-06	8.34
1.352	3694990.00	3.05E-06	8.70
1.372	3700960.00	3.37E-06	9.10
1.392	3706060.00	4.01E-06	9.52
1.414	3710530.00	4.97E-06	9.97
1.435	3714260.00	5.59E-06	10.47
1.457	3717390.00	6.96E-06	10.95
1.479	3719930.00	8.65E-06	11.45
1.502	3722000.00	1.13E-05	11.99
1.531	3723200.00	2.41E-05	12.61

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